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THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant.
—*Novum Organum, Præfatio.*

VOLUME THE SIXTY-NINTH.

1913.

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CORRIGENDA.

P. lxxxviii, in the List of Borings, seventh column, opposite 'Meux's Brewery,' *for* 'Lower Greensand, 64' *read* 'Great Oolite Series, 64.'

P. 200, last line of the footnote, *for* 'Whitby' *read* 'Whitley.'

Dates of Issue of the Quarterly Journal for 1913.

No. 273—April 25th, 1913.
No. 274—July 29th, 1913.
No. 275—October 29th, 1913.
No. 276—January 20th, 1914.

Vol. LXIX. MARCH 1913. No. 273.
Part 1.

THE

QUARTERLY JOURNAL

OF THE

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EDITED BY

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[With Twenty-one Plates, illustrating Papers by Mr. H. W. Monckton, Mr. E. S. Cobbold, Mr. Stanley Smith, Dr. A. S. Woodward, Prof. A. C. Seward, and Mr. C. Dawson & Dr. A. S. Woodward.]

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[*Business will commence at Eight o'Clock precisely.*]

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THE

QUARTERLY JOURNAL

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VOL. LXIX.

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1. *The* LOWER PALÆOZOIC ROCKS *of the* CAUTLEY DISTRICT (YORKSHIRE). By JOHN EDWARD MARR, Sc.D., F.R.S., F.G.S. (Read December 4th, 1912.)

THE object of this paper is to establish a more detailed succession for the Ordovician rocks of the district, and to offer some notes upon the faunas of the Silurian rocks, the detailed succession of which has already been established.

I wish to thank the members of a party who accompanied me on an excursion, for much help in collecting. They were Messrs. A. W. R. Don, W. B. R. King, R. U. E. Knox, T. C. Nicholas, J. Romanes, and Bernard Smith. My son, F. A. Marr, has also rendered much assistance on several occasions. Fossils were collected on Sally Brow many years ago by Prof. McKenny Hughes, and Mr. Fearnsides has also supplied several specimens. I would especially thank Mr. J. Middlebrook, who placed his valuable local collection at my disposal, and ultimately presented it to the Sedgwick Museum.

I am greatly indebted to Miss G. L. Elles, D.Sc., for her kindness in identifying the Ordovician graptolites.

The Geological Survey Memoir, 'The Geology of the Country around Mallerstang . . . .,' explanatory of Quarter-Sheet 97 N.W. (n. s. Sheet 40), has naturally been of great use. In this memoir a bibliography of the geology of the area up to the time of its publication (1891) is given; this renders it unnecessary to append one here.

Some brief notes on the rocks by myself and Mr. W. G. Fearnsides were published in the Report of the British Association (Sheffield) 1910, p. 603.

It will be well to give here a table of the strata as developed in the Cautley district:—

SILURIAN	Salopian	Lower Ludlow	Bannisdale Slates.
			Coniston Grits (in a restricted sense).
			Coldwell Beds.
		Wenlock	Brathay Flags.
	Valentian	Tarannon	Stockdale Shales.
		Llandovery	
ORDOVICIAN	Ashgillian.		
	Caradocian.		

A. The Ordovician Strata.

A reference to the Geological Survey map shows that these strata are developed in three elliptical patches in the form of an inverted L, with a strip running southwards from the end of the north-westerly mass. As these ellipses are denuded domes, the Caradocian rocks, on the whole, form the central portions, and the Ashgillian beds their peripheries; but, as there is much folding and faulting, there are naturally exceptions to this general statement.

One of the most satisfactory exposures is developed in Backside Beck, which cuts through the north-westerly dome in a general north-and-south direction. As the south-eastern side of this dome is faulted out, there is an ascending sequence as one proceeds up stream. This section will constitute the type-section, and afterwards other sections will be described, which are confirmatory of the succession established in the beds of Backside Beck.

No attempt will be made to estimate the thickness of the rocks. They certainly include several hundreds of feet of strata.

A very detailed account of the section is given in the Geological Survey Memoir (pp. 20–26). Fig. 1 (p. 6) shows the subdivisions which I propose to make.

The lowest beds are blackish shales, with impure blue-black limestones, which extend from the south-eastern end of the dome for a considerable distance up stream. The exact junction of these beds with those that succeed them has not been determined in this beck; but the lower beds extend at least as far as a point a few yards south of a ruined footbridge mentioned in the Survey Memoir. This bridge is 350 yards south-south-west of Mountain-View Farm. Up to a point near the footbridge the beds yielded a Caradocian assemblage of fossils. The following have been obtained:—

Trinucleus seticornis His.? (common).
Remopleurides sp. (rare).
Illænus bowmanni Salt.?
Cybele verrucosa Dalm.
Calymene planimarginata Reed (common).
Orthis calligramma Dalm.
Plectambonites sericea Dalm.

The most abundant fossil here, as elsewhere in these beds of the district, is the *Calymene.* The form is that recorded by Salter as *C. senaria* Conrad in the Sleddale Beds of the Lake District. Mr. F. R. C. Reed has, however, shown that the form is not Conrad's species, and has given it a new name, *C. planimarginata.*[1] From its abundance, the beds will be referred to as the *Calymene* Beds. I have hitherto found no form of this or any other species of the genus in higher Ordovician deposits of the Cautley neighbourhood; it is, therefore, a particularly characteristic fossil.

Above the highest exposure with *Calymene* a considerable thickness of similar strata occurs, which has yielded, so far, neither the *Calymene* nor any characteristic fossil of the succeeding beds; and in Backside Beck, therefore, one cannot, within a limit of 100 feet or more, draw a line of demarcation between the *Calymene* Beds and the succeeding strata, to be next described. In other words, it is not at present possible to indicate here the exact line of separation between the Caradocian and the Ashgillian strata. The first characteristic assemblage of Ashgillian forms has been found about 300 yards higher up the stream than the point yielding the last *Calymene*; as, however, the strike is, for some distance, nearly parallel to the stream, and a considerable stretch is occupied by a felsite sill, the thickness is not very great. The evidence, on the whole, is in favour of the beds immediately above the ruined footbridge belonging to the lowest Ashgillian group. Impure limestones and calcareous shales immediately above the bridge have yielded *Turrilepas*; and a little higher up, just below the felsite sill, a specimen of *Strophomena corrugatella* occurred. Lithologically, the beds suggest rather Ashgillian than Caradocian deposits, but one cannot lay much stress upon this point.

Where the northern wall of a pasture west of the beck comes down to the stream, beds occur with *Remopleurides* and *Phacops robertsi*, striking generally along the stream to the junction of Watley Gill, where they form a cliff on the right bank of Backside Beck. These beds are lithologically similar, on the whole, to those of the *Calymene* Group. Like the latter, they consist of shales and impure limestones. The shales, however, are generally lighter in colour, grey rather than black, and have an unctuous feel; but individual bands are quite similar to some of the *Calymene* Beds.

Similar as are the lithological characters of the two groups, their faunas are markedly different, and the fossils of the upper group have a distinctly Ashgillian facies. *Remopleurides* and *Phacops robertsi* occur throughout, the latter being most abundant near the base. I shall speak of these beds as the *Phacops-robertsi* Beds.

Fossils occur in the limestones as well as in the shales, and, although in the former they are usually fragmentary, the details of structure and ornament are beautifully preserved. The following is a list of forms found in the *Phacops-robertsi* Beds of the beck :—

[1] See 'Lower Palæozoic Trilobites of Girvan' pt. 3, Monogr. Palæont. Soc. (1906) p. 137.

Monticuliporoids.
Dicellograptus anceps Nich.
Turrilepas.
Trinucleus seticornis (?).
Ampyx tumidus Forbes?
Remopleurides (Caphyra) radians Barr. (one specimen).
R. (Caphyra) sp. 1 (very abundant).
Remopleurides (sensu stricto) sp. 2 (two specimens).
Illænus.
Phillipsinella parabola Barr. (frequent).
Lichas.
Cybele rugosa var. *attenuata* Reed?
Phacops (Dalmannites) robertsi Reed (very common).
Phacops (Pterygometopus?) sp. (rare).
Phacops (Acaste) cf. *downingiæ* Murch. (common).

The succeeding beds will be spoken of as the *Staurocephalus* Beds, although the index-genus has not hitherto been detected below the contemporaneous volcanic rocks which occur near the middle of the division so named.

A few yards above the mouth of Watley Gill the main beck shows a passage from the *Phacops-robertsi* Beds into hard, blue, flaggy mudstones which extend up stream to the point where the beck leaves the moorland above to enter the highest part of the enclosed ground up which we have been tracing it.

On reaching the moorland, we note that calcareous beds become important; and a thick white limestone, with fragmentary fossils, recalls, as regards lithological characters, the Keisley Limestone.

I shall speak of the strata from the top of the *Phacops-robertsi* Beds to the base of the volcanic group as the 'beds below the volcanic group.' They have yielded here:—

Dicellograptus anceps.
Climacograptus normalis Lapw.
Glyptograptus persculptus Salt.
Tentaculites anglicus Salt.
Ateleocystites (?).
Trinucleus.
Illænus.
Orthis.

Above the beds just described comes the contemporaneous volcanic group, of which a full description is given by Dr. Strahan in the Geological Survey Memoir. It is associated with fine ashy calcareous shales, which weather olive-green.

Similar ashy shales weathering green, among which are intercalated thin calcareous bands, extend above the lavas and coarser volcanic ashes to a point about 200 yards below the junction of the upper tributaries of Backside Beck, namely, Spengill and Stockless Gill. They are succeeded by grey-blue pencil slates, the normal Ashgill Shales. The beds between the volcanic group and the Ashgill Shales will be spoken of as the 'beds above the volcanic group.' In Backside Beck they have yielded the following fossils:—

Dicellograptus anceps.
Dicellograptus sp.
Climacograptus normalis.
Orthograptus truncatus var. *abbreviatus* Elles & Wood.
Mesograptus modestus Lapw.?
Nymphograptus (?).
Retiolitid.
Agnostus trinodus Salt.
Trinucleus seticornis (?).
Ampyx.
Dindymene hughesiæ Roberts?
Sphærocoryphe thompsoni Reed.
Staurocephalus globiceps Portl.?
Skenidium.
Conularia.

Just below the Ashgill Shales, and forming the very top of the beds above the volcanic series, about 10 feet of argillaceous limestone

is seen in the stream-bed. It is unweathered, and I could find no fossils in it; but it probably represents an important band in Watley Gill and Oddgill, described elsewhere.

The Ashgill Shales of Backside Beck are not very fossiliferous, save the bands with *Phyllopora hisingeri* and *Myelodactylus* near the top. *Strophomena siluriana* Dav., with other brachiopods, and *Phacops mucronatus* Brongn., are not infrequent. I believe that all records of *Trinucleus* from the Ashgill Shales of this stream refer to specimens obtained from lower beds, which have hitherto been partly referred to the Ashgill Shales.

Before leaving the beck, I may say that I doubt the identification of *Phacops brongniarti* which I previously made. The specimen is unfortunately lost.

To sum up, the Backside-Beck section gives us the following sequence:—

ASHGILLIAN ...	Upper: Ashgill Shales (with *Phyllopora* Beds near the top).	
	Middle: *Staurocephalus* Beds	Beds above the volcanic group.
		Contemporaneous volcanic group.
		Beds below the volcanic group.
	Lower: *Phacops-robertsi* Beds.	
CARADOCIAN ...	*Calymene* Beds.	

Confirmatory Sections.

Watley Gill.—Starting from the junction with Backside Beck, the *Phacops-robertsi* Beds are exposed for a few yards up the tributary in its wooded portion, and pass up into blue flags, which are well seen opposite the sheepfold, and continue for many yards up stream. These are the beds below the volcanic group. They have yielded *Climacograptus normalis*, with crushed brachiopods, lamellibranchs, and phyllocarida.

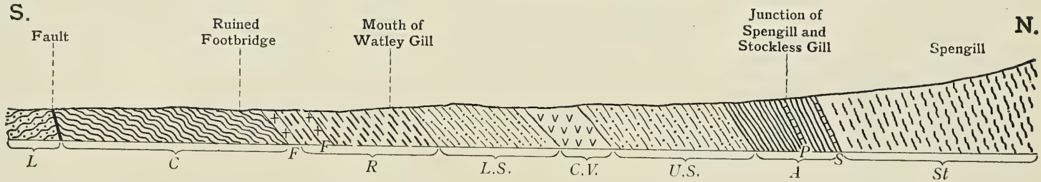
The contemporaneous volcanic group follows, succeeded by calcareous shales weathering olive-green, as in Backside Beck. The latter are much penetrated by lamprophyres, and fossils are ill-preserved, with one important exception to be noted immediately. The beds do not appear to be so thick as in Backside Beck, and some are probably faulted out.

At the extreme summit of these beds, above the volcanic group and immediately below the ordinary 'pencil-slate' Ashgill Shales, are calcareous beds with *Phacops mucronatus* and abundant Cystidea. The following were found:—

Caryocystites davisi M'Coy.	*Phacops mucronatus.*
Hemicosmites squamosus Forbes.	*Leptæna.*
Echinosphærites aurantium Forbes?	*Orthis.*
Turrilepas.	*Conularia* (?).

This deposit may be referred to as 'the *mucronatus* band of the *Staurocephalus* Group.' It is marked by the first appearance of

Fig. 1.—*Section in Backside Beck from the Ludlow Fault to Spengill.* (*Horizontal scale: 4 inches = 1 mile.*)



L = Lower Ludlow Beds.
St = Stockdale Shales.
S = Basal Silurian limestone.
} Silurian.

A = Ashgill Shales, with *Phyllopora* Beds at P.
U.S. = Beds above the contemporaneous volcanic rocks.
C.V. = Contemporaneous volcanic rocks.
L.S. = Beds below the contemporaneous volcanic rocks.
} *Staurocephalus* Beds.
} Ashgillian.
R = *Phacops-robertsi* Beds.
C = *Calymene* Beds (Caradocian).
F = Intrusive felsites.

Phacops mucronatus, a form which extends upwards into the Ashgill Shales, and also into the Stockdale Shales. It is probably the same band as that mentioned just below the Ashgill Shales of Backside Beck: its significance will be noted later.

The succeeding 'pencil-slate' Ashgill Shales are quite like those of Backside Beck and other localities in the district, and contain the usual fossils. Near the top is more than one band with *Phyllopora hisingeri*, as in Backside Beck. Above these come several feet of normal Ashgill Shales, with *Platystrophia biforata* Schloth. and other brachiopods, and also several Phyllocarida. In the shales is a calcareous grit, or possibly more than one, containing brachiopods, and resembling the grit described by Prof. Hughes at the junction of Spengill and Stockless Gill. At that place the bed seems to be now covered up.

The north-eastern dome.—The beds of this dome are much faulted, but the Caradocian strata, as a whole, occur in the centre, and are well developed in Sally Beck and its valley-sides. The beds are generally similar to those of Backside Beck; but, as many exposures are seen where the rocks are weathered, the fossils here are more easily extracted. The principal localities are at the bottom of Green Lane, east of Murthwaite, on the left bank of the beck; and Sally Brow, near Murthwaite, on the right bank. The following fossils have been obtained, those from Green Lane being numbered 1, and those from Sally Brow 2:—

Lindstrœmia. 2.
Heliolites tubulata Lonsd. 2.
Cystidea. 2.
Trinucleus seticornis (?).
Ampyx. 1.
Acidaspis cf. *dalecarlica* Törnq. 1.
Acidaspis sp. 2.
Stygina. 1.
Illænus. 1, 2.
Cybele rugosa Portl. 1.
Cybele verrucosa Dalm. 1, 2.
Calymene planimarginata. 1, 2 (very common).
Encrinurus multisegmentatus Portl. 2.
Proetus. 1, 2.
Homalonotus sedgwicki Salt. 2 (common).
Cheirurus octolobatus M'Coy? 2.
Phacops robertsi. 2 (two specimens).
Lingula. 2.
Platystrophia biforata. 2.
Orthis elegantula Dalm. 1, 2.
Orthis vespertilio Sow. 1, 2.
Orthis porcata M'Coy? 1.
Plectambonites sericea. 1, 2.
Triplesia insularis Eichw. 2.
Tentaculites anglicus. 2.

These beds undoubtedly yield the fauna of the *Calymene* Beds, but the presence of *Phacops robertsi* suggests that the beds of Sally Brow are high up in that group. Farther down stream the section has not been entirely unravelled. The beds begin to dip down stream, and continue with this general southerly dip until near Rawthey Bridge, where they turn over and dip north-westwards. It would, therefore, seem that, apart from complications, we are dealing with a syncline. In the southern limb, to be presently described, the succession is clear and continuous; but in the northern limb it is obscure, and we have only fossils from one locality, namely, the footbridge across Sally Beck, over which is the path to Murthwaite. Fossils were found here by Mr. Middlebrook. The

beds are of doubtful age, as no characteristic forms of either Ashgillian or Caradocian strata have been found; but the lithological characters and the general nature of the fauna suggest that the beds are Ashgillian, and belong to the *Staurocephalus* division. The rock is a grey encrinital limestone, weathering to an ashy-looking olive-green and brown rottenstone. It yielded:—

Remopleurides.	*Cybele verrucosa.*
Phillipsinella parabola (?).	*Phacops (Chasmops?)* sp.
Lichas laxatus.	*Orthis* (several species).
Illænus bowmanni (?).	*Strophomena corrugatella (?).*

If the beds on Sally Brow are high up in the *Calymene* Group, as suggested, the newer age of these footbridge strata is rendered still more probable.

We will pass now to the southern limb of this syncline, where the beds are well developed in the Rawthey, above and below the mouth of Sally Beck.

Above Rawthey Bridge, the section in the neighbourhood of the fault which lets down the Carboniferous rocks is obscure, but there is a general ascending succession down stream. *Phacops robertsi* was found in a cliff 100 yards above the bridge, in unctuous grey shales associated with light-coloured limestones, and the same fossil occurred under the bridge itself. About 30 yards lower down the stream, a small cliff on the left bank shows the beds in a weathered condition, and here fossils are plentiful. We found:—

Turrilepas.	*Phacops.* Two other species.
Remopleurides (Caphyra) sp. 1.	*Orthis.*
Phacops robertsi (very abundant).	

It is doubtful whether any of the beds up stream belong to the *Calymene* Group, but the fossiliferous beds just described are undoubtedly the *Phacops-robertsi* Beds.

Continuing down stream, on its left bank we observe a continuous exposure for a long distance. The beds above described pass into blue flags, which are penetrated by a lamprophyre. These, from their position and characters, are the lower division of the *Staurocephalus* Group, but have here yielded no fossils. No sign of the contemporaneous volcanic rocks was seen here, apart from the general ashy appearance of the calcareous shales, and Dr. Strahan has shown that the volcanic rocks die out southwards. Above the blue flags are olive-green ashy-looking mudstones resembling the beds above the volcanic group of Backside Beck. They set in near the eastern end of the wood which skirts the right bank of the stream, and are continued down stream until near the western end of the wood. The following fossils were found in these, the upper division of the *Staurocephalus* Beds (beds above the volcanic group):—

Dicellograptus anceps.	*Cybele rugosa* var. *attenuata (?).*
Glyptograptus persculptus.	*Orthis.*
Climacograptus normalis.	*Leptæna.*
Trinucleus bucklandi Barr. (?).	*Tentaculites anglicus.*
Dindymene hughesiæ (?).	

Below the wood there is a short interval with no exposure, and then the Stockdale Shales are seen. The interval seems too small to allow of a full development of the Ashgill Shales, and there is probably a fault at the base of the Silurian strata.

Another development of Ashgillian rocks is found in this dome in Oddgill, a tributary of Wandale Beck north of Murthwaite. The beds here are separated from those last described by a fault, as noted in the Geological Survey Memoir.

The lower part of Wandale seems to be in Caradocian strata, but no fossils have been found. The first fossils met with were in rocks developed in Wandale Beck, 75 yards below the mouth of Oddgill. These are of the same nature as those exposed in Backside Beck and the Rawthey, and yielded :—

Dicellograptus anceps.
Orthograptus truncatus var. *abbreviatus.*
Trinucleus.
Phacops robertsi.
Lingula.

These deposits belong to the beds below the volcanic group. At the mouth of Oddgill, as noted in the Survey Memoir, the contemporaneous volcanic group is seen, and higher beds are observed in passing up this gill. These have the lithological characters of the beds above the volcanic group, but we obtained no fossils from them. They occur in the wooded portion of the gill, where they are broken through by a large felsite sill, and continue upwards on to the moorland. Where a little stream enters Oddgill from the north, the *mucronatus* band at the top of the *Staurocephalus* Beds is seen, having the same characters as at Watley Gill. It yielded :—

Hemicosmites squamosus.
Echinosphærites arachnoideus (?).
Turrilepas.
Cheirurus.
Phacops mucronatus.
Phacops (Acaste) apiculatus Salt.

Above these beds, in the little tributary, is a poor exposure of leaden-blue shales, which are almost certainly Ashgill Shales. Beyond this, the section is covered by drift.

The south-eastern dome.—In this dome important sections are seen in Taythes Gill and its tributaries. The lower part of the gill (known as Ecker Secker Beck) certainly contains Ashgillian rocks; but, before entering the moorland, Caradocian Beds are seen. These occupy the core of the dome. The accompanying sketch-plan (fig. 2, p. 10) of that part of Taythes Gill and its tributaries which lies around Taythes House shows the relationship of the Caradocian and Ashgillian strata. On the right bank of the gill, just opposite the bridge leading to Taythes House, are weathered *Calymene* Beds containing abundantly the index-fossil. Farther down stream is a thick sill of felsite, and immediately below this are unctuous grey shales and limestones with *Phacops robertsi.* There is not room for more than a few feet of strata between the highest beds with *Calymene* and the lowest *Ph.-robertsi* Beds ; and so here we are able to draw a fairly sharp line between the Caradocian and the Ashgillian.

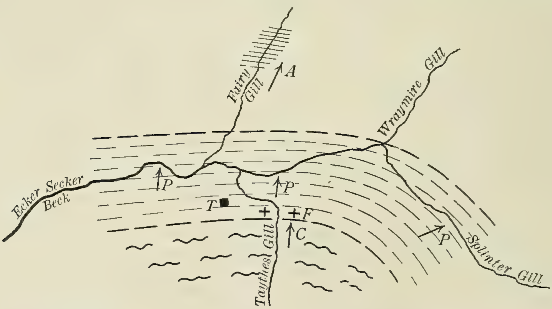
The *Phacops-robertsi* Beds are well exposed in Wraymire Gill, immediately before it joins Taythes Gill, and are here fairly fossiliferous. Hence they strike westwards to a point in Taythes Gill above a footbridge on the west side of Fairy Gill, and eastwards into Splinter Gill, where they are again seen. In all these localities they are very fossiliferous, and the following forms have been found:—

Dicellograptus anceps. 2, 3.
Glyptograptus persculptus. 3.
Ampyx. 3.
Trinucleus seticornis (?). 1, 2, 3.
Dionide euglypta Barr.? 2.
Remopleurides (Caphyra) sp. 1. 1, 2, 3 (very common).
Illænus. 2.
Lichas. 3.
Phacops robertsi. 1, 2, 3 (very common).
Phacops apiculatus (?). 2.
Phacops cf. *downingiæ.* 2.
Turrilepas. 1.
Lingula. 2.
Orthis. 1, 2, 3.
Leptæna. 2.
Conularia. 1.

1 = Wraymire Gill; 2 = Taythes Gill, west of Fairy Gill; 3 = Splinter Gill.

No *Staurocephalus* Beds or Ashgill Shales are seen in the upper part of Taythes Gill, where the *Calymene* Beds are faulted against Stockdale Shales; nor in Wraymire and Splinter Gills, the heads of which are filled with drift. Drift also covers the lower part of

Fig. 2.—*Plan of streams at Taythes, on the scale of 6 inches to the mile.*



A = Ashgill Shales.
P = *Phacops-robertsi* Beds.
C = *Calymene* Beds.
F = Felsite.
T = Taythes House.
[The letters A, P, C are placed alongside arrows showing localities where fossils were found.]

Fairy Gill, and doubtless conceals the *Staurocephalus* Beds: for the well-known sections of Ashgill Shales of Fairy Gill are dipping away from the *Phacops-robertsi* Beds which are above described. Hence no continuous section of Ashgillian strata, like that found in Backside Beck, has been detected in Taythes Gill.

B. The Silurian Strata.

Stockdale Shales.—In a paper on these beds by the late Prof. Alleyne Nicholson and myself, a limestone 6 inches thick was described as occurring at the base of these shales in Backside Beck. There the Ashgill Shales are seen immediately below it; we have now found fossils in the limstone itself, and they are:—

Encrinurus punctatus var. *arenaceus* Marr & Nich. ?	*Leptæna* cf. *quinquecostata.*
Cheirurus bimucronatus Murch. var. ?	*Orthis*, two spp.
Phacops mucronatus.	*Strophomena*, two spp.
	Hyolithes.

In the note communicated by Mr. Fearnsides and myself to the British Association at Sheffield in 1910, it was stated that an important section of the Skelgill beds of the Stockdale Shales occurs in Watley Gill. Of this I propose to give some further details.

The basal limestone just noticed is here seen badly exposed on both banks immediately above the Ashgill Shales. From it we obtained:—

Cyphaspis cf. *rastritum* Törnq.	*Phacops mucronatus.*
Acidaspis.	*Hyolithes.*

Above it are the shales of the *Dimorphograptus* Zone with badly-preserved graptolites, which, however, are sufficiently determinable to indicate the zone. This is succeeded by the shales of the *Monograptus-fimbriatus* Zone with that fossil, *M. cyperoides* Törnq., and *Diplograptus mutabilis* Elles & Wood ?

Above this come the hard mudstones of the *Encrinurus* Zone, followed by the shales of the *Monograptus-argenteus* Zone. The latter is much crushed, but a little thinner than in the Lake District. It contains the 'green streak,' also slightly thinner than in that district.

The fossils obtained from this zone are:—

Monograptus argenteus Nich.	*Monograptus gregarius* Lapw. ?
M. leptotheca Lapw.	*Rastrites hybridus* Lapw.
M. convolutus His.	*Climacograptus hughesi* Nich.
M. nicoli Harkn.	*Diplograptus sinuatus* Nich.
M. limatulus Törnq.	*Diplograptus bellulus* Törnq.
M. communis Lapw.	

It is succeeded by the *Phacops-glaber* Zone, from which my son obtained a tail of that form; and above the beds of that zone are the shales of the *Monograptus-convolutus* Zone, from which we extracted the index-species and some of its usual accompaniments. A fault here brings up the *Dimorphograptus* Beds once more, and above this there is no further exposure in the gill.

In the south-eastern dome the basal limestone of the Stockdale Shales occurs in Birks-Wood Gill, a little distance above the road. It here resembles the same limestone as seen in the Lake District, and contains brachiopods; but no specimens sufficiently perfect for determination have been found.

Wenlock Beds.—The graptolitic succession of these beds has recently been described by Miss Watney & Miss Welch,[1] and no further remarks are necessary concerning the graptolites. Other fossils are rare, save some obscure brachiopods and cephalopods; but my son discovered the head of an *Arethusina* in an exposure of the *Cyrtograptus-murchisoni* Zone of Middle Gill. (See Appendix, p. 16.)

Lower Ludlow Beds.—Here again, the graptolitic succession has been described by the above-named authors, who note the occurrence of the *Phacops-obtusicaudatus* Beds. In these beds a fairly rich fauna has been discovered, including the following fossils:—

Acidaspis. 1, 2.
Encrinurus variolaris Brongn. var.? 2.
Proëtus. 1, 2.
Phacops obtusicaudatus Salt. (common wherever the beds are exposed).
Phacops sp. 1. 1, 2.
Phacops sp. 2. 1.
Leptæna. 1, 2.
Orthis. 1.
Orthoceras, various species (frequent).

1=North-north-west of Narthwaite.
2=River Rawthey, below the entrance of Backside Beck.

These beds are the Middle Coldwell Beds of the Lake District. It is doubtful whether the Lower Coldwell Beds are developed at Cautley.

The Upper Coldwell Beds form, at any rate, part of the *Monograptus-nilssoni* Zone. They contain other fossils, such as *Cardiola*, but no important collection has been made from them.

The Bannisdale Shales with *Monograptus leintwardinensis* also contain numerous fossils other than graptolites, but I have nothing to add to the lists given in the Geological Survey Memoir. There is much work yet to be done in collecting fossils from all the Lower Ludlow rocks of the district.

One deposit of Silurian age may be noted, although its exact horizon has not been established. In Screes Gill, on the south-western slopes of Yarlside, Mr. Middlebrook has found beds of gritty white limestone, much contorted, but certainly many feet thick. The fossils that have been obtained are poorly preserved and do not indicate the horizon of the limestone, which is probably, however, very low down in the Lower Ludlow succession.

C. Relationship of the Ashgillian Beds to those of other Areas.

In the first place, it is evident that the Ashgillian Series is the zone of *Dicellograptus anceps*. This fossil appears in the *Phacops-robertsi* Beds and passes into the *Staurocephalus* Beds, being found both above and below the contemporaneous volcanic rocks. No graptolites have occurred in the Ashgill Shales.

[1] Q. J. G. S. vol. lxvii (1911) p. 215.

The above-mentioned graptolite has been found in the Desert-creat Beds of Tyrone.[1] It has also been recorded by me in the beds at Norber Brow in the Settle District.[2] There is no doubt that these beds are Ashgillian, and represent the *Staurocephalus* Beds of the Cautley District.

In the Lake District, I divided the Ashgillian Series into a lower group, *Staurocephalus* Limestone, and an upper, Ashgill Shales.[3] The identity of the Ashgill Shales in that and the Cautley districts is clear, but the *Staurocephalus* Limestone of Lakeland presents the lithological characters and fauna of the uppermost division only of the Cautley *Staurocephalus* Beds (the *Phacops-mucronatus* Band).

The fauna of the bulk of the *Staurocephalus* Beds and of the *Phacops-robertsi* Beds appears to be wanting in Lakeland. This may be due to an unconformity (which occurs below the Ashgillian Series in South Wales), or some of the beds referred to the Sleddale Group may be really Ashgillian. I suspect the former, but further work is required in Lakeland.

In the Cross-Fell inlier it is more probable that some of the beds referred to the Sleddale Series are actually Ashgillian. It may be noted that the Sleddale (*Calymene*) Beds of Cautley lithologically resemble those of the Cross-Fell inlier more than those of Lakeland; and I suspect, from the occurrence of certain fossils high up in the Dufton Shales of Swindale Beck, that the upper part of the Dufton Shales may have to be removed from the Sleddale Group (Caradocian) and placed in the Ashgillian.

The succession in South Wales can at present be more satisfactorily compared with that of Cautley. The *Staurocephalus* of Pelcombe Cross is unaccompanied by *Phacops robertsi*, and, conversely, the former fossil is not recorded from the *Ph.-robertsi* Beds of Prendergast. It would seem that the beds termed 'Sholeshook Limestone Group' by the late Mr. T. Roberts & myself,[4] which include the above-named deposits, may be divisible into a lower and an upper series characterized by the *Phacops* and the *Staurocephalus* respectively. The similarity of the higher beds in the two areas has been noted by me,[5] and needs no further remark.

The notes in the paper just cited also render it needless to comment upon the relationship between the Ashgillian Series of Cautley and that of other areas.

In conclusion, the development of the Ashgillian Series in the North of England is far more satisfactorily shown around Cautley than in the neighbouring areas of the Lake District and Edenside; and I have described this Cautley succession as one which should be taken as the type for the Ashgillian Series of Northern England.

[1] See W. G. Fearnsides & others, Proc. Roy. Irish Acad. vol. xxvi, sect. B (1907) p. 111.
[2] Geol. Mag. dec. 3, vol. iv (1887) p. 36.
[3] *Ibid.* dec. 3, vol. ix (1892) p. 97.
[4] Q. J. G. S. vol. xli (1885) p. 480.
[5] Geol. Mag. dec. 5, vol. iv (1907) p. 65.

D. Appendix—Notes on the Fossils.

In the lists given in the paper, a large number of forms are queried, or compared with forms to which they present near affinities. I have no doubt that many of these are new; but, considering the fragmentary nature of the material at my disposal, I do not feel inclined to create new species.

The names of the brachiopods are chiefly names which in many cases cover several forms now included in one species. With regard to these brachiopods, it is noteworthy that the large *Orthides* and *Strophomenæ* occur in great profusion in the Caradocian rocks, but are rare in Ashgillian strata below the Ashgill Shales, being replaced by much smaller, often minute forms.

The vague determinations are given in the lists, in the hope of directing the attention of collectors to an area which will undoubtedly yield a rich harvest. When this is reaped, the palæontology of the Ashgillian Series of the area can be elucidated in detail. The peculiarly rich and well-preserved fauna of the limestones of the *Phacops-robertsi* Beds will in particular well repay prolonged search. In the meantime, the lists here tabulated will suffice to indicate the dominant forms, and show the marked differences between the Caradocian and the Ashgillian faunas of the Cautley District; they also enable us to correlate the beds with those of other areas.

All the fossils referred to in the paper are preserved in the Sedgwick Museum, Cambridge.

(1) Fossils of the *Calymene* Beds.

Echinosphærites stellulifer Salt.—A specimen bearing this name is preserved in the Sedgwick Museum. It was probably collected by Sedgwick, and is from 'Ravenstonedale.' It is probable that it came from the *Calymene* Beds, as the other specimens collected by Sedgwick from this tract are from these beds. The Sally Beck basin was included in Ravenstonedale by Sedgwick, and no Ordovician strata occur in Ravenstonedale proper.

Isolated plates of Cystidea are not uncommon in the *Calymene* Beds. One from Sally Brow closely resembles the form described by M'Coy[1] as *Acanthalepis jamesii*, which, as Edward Forbes suggests,[2] is almost certainly cystidean.

Trinucleus.—See p. 15.

Remopleurides (*sensu stricto?*) sp.—Fragments of *Remopleurides* have been found in the *Calymene* Beds of Taythes Gill and Backside Beck.

An external cast showing six of the body-segments and traces of two others comes from Taythes Gill. Axis and pleura alike are ornamented with wavy lines at right angles to the length of the

[1] 'Synopsis Silur. Foss. Ireland' 1846, p. 7 & pl. i, figs. 1–2.
[2] Mem. Geol. Surv. vol. ii (1848) p. 511.

trilobite. A specimen from Backside Beck is a portion of a glabella well preserved in limestone. It shows no sign of glabellar furrows. A single pleuron from this locality differs from the pleura of the Taythes Gill specimen in the direction of the lines, which are parallel to the long axis of the animal. Two species may be indicated.

PHACOPS ROBERTSI Reed.—The occurrence of two specimens in the Caradocian beds of Sally Brow marks the arrival of a form peculiarly abundant in the lowest Ashgillian strata. The species is, however, obviously very rare in the *Calymene* Beds, for much material has been broken up.

(2) Fossils of the *Phacops-robertsi* Beds.

TRINUCLEUS (TETRASPIS).—The subgenus is abundant in the *Calymene* Beds of the Caradocian Series and in the *Phacops-robertsi* and *Staurocephalus* divisions of the Ashgillian. I have handed over the material to Mr. F. R. C. Reed, who is at present engaged in studying the genus, and need only remark here that the somewhat imperfect specimens from the Caradocian agree with forms usually referred to *Tr. seticornis*. This is also the case with those from the *Phacops-robertsi* Beds. In these forms the fringe ends near the posterior angle of the head, and a simple spine extends backwards. In the *Staurocephalus* Beds a form is common which has the fringe prolonged backwards sometimes as far as the pygidium, as in Barrande's *Trinucleus bucklandi*.

REMOPLEURIDES (CAPHYRA) sp. 1.—This form apparently differs from any species hitherto described.

The anterior tongue is much longer than that of the form figured by Barrande, but agrees fairly with the tongues figured by Linnarsson [1] and Olin.[2] The ornamentation is quite different from that on Barrande's specimens, and also from that in pl. i, fig. 21 of Linnarsson's paper. Head, body-rings, and tail alike are marked by wavy transverse lines; similar lines are seen in *R. portlocki*, figured by Mr. F. R. C. Reed from the Tramore Limestone of Waterford,[3] and in *R. latus* Olin [4]; the other characters of the species here described are different from those of these forms.

Three pygidia have been found, which, apart from the ornamentation, are too imperfect to show the characters.

This species is extraordinarily abundant in the *Phacops-robertsi* Beds.

[1] K. Svensk. Vetensk.-Akad. Handl. vol. viii (1869) No. 2, p. 67 & pl. i, figs. 21–22.

[2] Meddelande från Lunds Geol. Fältklubb, sect. B (1906) p. 54 & pl. ii, figs. 1–2.

[3] Q. J. G. S. vol. lv (1899) p. 746 & pl. xlix, fig. 4.

[4] E. Olin, *op. cit.* pl. ii, figs. 6, 8, & 9.

Remopleurides (*sensu stricto*) sp. 2.—Two fragments of heads from the limestone of Backside Beck, at its junction with Watley Gill, belong to this subgenus. They are marked by a very broad neck-ring. They are also marked by transverse wavy lines like those of the last form.

Remopleurides sp.—A large form occurs in beds of doubtful age, at the footbridge to Murthwaite over Sally Beck. One has eight body-segments preserved, the other nine and a fragment of the pygidium. It is interesting to note that one of two specimens found has a broad, the other a narrow, axis, as is so frequently the case with species of this genus.

Illænus sp.—A pygidium from Taythes Gill does not appear to agree with that of any described British species. It closely resembles an unnamed form figured by Prof. Brögger from the Ordovician beds of Espehoug, in the Trondhjem district.[1]

(3) Fossil from the *Cyrtograptus-murchisoni* Zone (Wenlock).

Arethusina sp.—The discovery by my son of a head from the *Cyrtograptus-murchisoni* Zone of Middle Gill adds another record for this rare British form. It had previously been recorded by Mr. F. R. C. Reed from the Balclatchie Beds of Girvan.[2] He refers this doubtfully to Barrande's *A. konincki*. In addition to that species, we know *A. nitida* Barr. from the Ludlow Beds of Bohemia, a pygidium only being figured; *A. sandbergeri*, also described by Barrande from the Devonian beds of Hagen (Westphalia)[3]; a form referred to *A. konincki* from the *Retiolites* Beds of Dalecarlia[4]; and one described by Prof. Frech under the name of *A. haueri*.[5] This last is a Silurian form, but its exact horizon is a matter of dispute. It comes from an *Orthoceras* Limestone at Kok in the Eastern Alps, which is equivalent to part of our Wenlock or Lower Ludlow Beds.

Prof. Törnquist notes some minor variations between his form and the typical Bohemian *konincki*. Prof. Frech's species is stated to differ from *konincki* by its considerably arched glabella, its rounded cheeks, the transverse furrows on the further side of the glabella (which do not reach the eyes), and the smaller margin of the head-shield. Our form resembles Frech's (and also Törnquist's?) in the arched glabella; but it differs from *A. haueri* in having the

[1] W. C. Brögger, 'Om Trondjhemsfeldtets midlere Afdeling mellem Guldalen & Meldalen' Vidensk.-Selsk. Forhandl. (Christiania) 1877.

[2] 'Lr. Palæozoic Trilobites of Girvan' pt. 2, Monogr. Palæont. Soc. vol. lviii (1904) p. 84.

[3] J. Barrande, 'Réapparition du Genre *Arethusina* Barr.' Prague, 1868.

[4] S. L. Törnquist, 'Undersökn. öfver Siljansområdets Trilobitfauna' Sver. Geol. Undersökn. ser. C, No. 66 (1884) p. 51.

[5] F. Frech, Zeitschr. Deutsch. Geol. Gesellsch. vol. xxxix (1887) p. 736.

cheeks prolonged into spines, and the transverse furrows reach the eyes. Until further specimens are discovered, it will be best to leave it unidentified.

(4) *Phacops-obtusicaudatus* Beds.

Several forms of *Phacops* (including *Dalmannites*) occur in these beds. In addition to the typical *Ph. (D.) obtusicaudatus* are the following :—

Phacops (Dalmannites?) sp. 1.—A pygidium and imperfect body-ring from north-east of Narthwaite evidently belong to one species; and, from the character of its ornamentation, a head from the left bank of the Rawthey probably belongs to the same form. It is noticed here on account of the character of the tail, the border of which is not entire. Each fused segment is prolonged into a denticulate extremity, very marked in the case of the two anterior segments, but obscure in the hinder segments. The axis and limb are ornamented with rows of elongated tubercles, which, judging from the cast, were short spines. A similar ornamentation is seen on the body-ring.

The form approaches *Cryphœus*, which, according to J. W. Salter's diagnosis,[1] differs from *Dalmannites* only in the character of the tail. He later comments upon 'the folly of classifying the Trilobites by such a character as the pattern of the tail.'

It is interesting to note that Prof. E. Kayser[2] describes, under the name of *Thysanopyge argentina*, a tail from *Didymograptus*-bearing beds of South America, which carries somewhat similar denticulate extensions, and, in addition, a long terminal mucro.

Phacops (Dalmannites) sp. 2.—A form was recorded by me[3] from the *Obtusicaudatus* Beds of Lakeland, under the name of *Ph. torvus* Wyatt-Edgell. This form is common at Narthwaite. I cannot find the specimen of *Ph. torvus* of Wyatt-Edgell which led me to make this identification. The fossil recorded by that name in the Museum of Practical Geology is a true *obtusicaudatus*.

Discussion.

Miss G. L. Elles drew attention to the unity of the Ashgillian as regards its graptolitic facies; she pointed out that its graptolitic fauna, though in some respects of the nature of a passage-fauna between the Bala on the one hand and the Llandovery on the other, had some distinctive characters of its own. With the advent of this fauna the many-branched *Pleurograptus*, *Leptograptus*, and the large *Diplograpti*, so especially characteristic of the Bala, died away; while its upper limit was defined by the incoming of *Monograpti*. She also suggested that parallelism with the classic areas

[1] 'Monogr. Brit. Trilob.' Palæont. Soc. (1864) p. 15.
[2] Zeitschr. Deutsch. Geol. Gesellsch. vol. 1 (1898) p. 425.
[3] Geol. Mag. dec. 3, vol. ix (1892) p. 537.

of the South of Scotland was not to be expected, because the conditions of deposition there, in early Ashgillian times at any rate, were unfavourable to life; hence the fauna was dwarfed or stunted, and not typical. If the conditions had been favourable, the fauna of the *Dicellograptus-anceps* Zone might have been found at a lower horizon.

Mr. HERBERT H. THOMAS felt sure that he was voicing the feelings of all workers on the Lower Palæozoic rocks in saying how grateful he was to the Author for, in the first place, giving to Geology his Ashgillian Series, and now for this piece of work which would add still more to the value of the Ashgillian Series as a geological division.

The PRESIDENT (Dr. A. STRAHAN) referred to the admirable pioneer work which had been done by Prof. T. McKenny Hughes in this region. The term Ashgillian suggested by the Author had proved convenient, and had been adopted in some of the Geological Survey publications relating to South Wales. The additional precision which had been given to it in this paper was of much value.

2. *On the* Hafslo Lake *and the* Solvorn Valley (Norway). By Horace Woollaston Monckton, Treas.L.S., F.G.S. (Read November 20th, 1912.)

[Plate I.]

The district dealt with in the present communication is situated in the North Bergenhus Amt, in Western Norway. It lies north of the main part of the Sogne Fjord and west of its innermost branch, the Lyster Fjord. An account of the locality, under the heading 'Lysterfjorden og Hafslo,' will be found in the admirable paper by Dr. Reusch entitled 'Nogle Bidrag til Forstaaelsen af hvorledes Norges dale og fjelde er blevne til,' which is provided with a summary in English.[1]

A geological map of Southern Norway by Dr. K. O. Björlykke will be found in his work 'Det centrale Norges Fjeldbygning;'[2] and another geological map, on a larger scale, which takes in the present district, has been published by Dr. Reusch.[3] The map which I give (fig. 1, p. 20) is merely a sketch-map, founded on the Topographical Map of Norway, Sheet 29 B (Sogndal), with the geology sketched in from the above-mentioned geological maps.

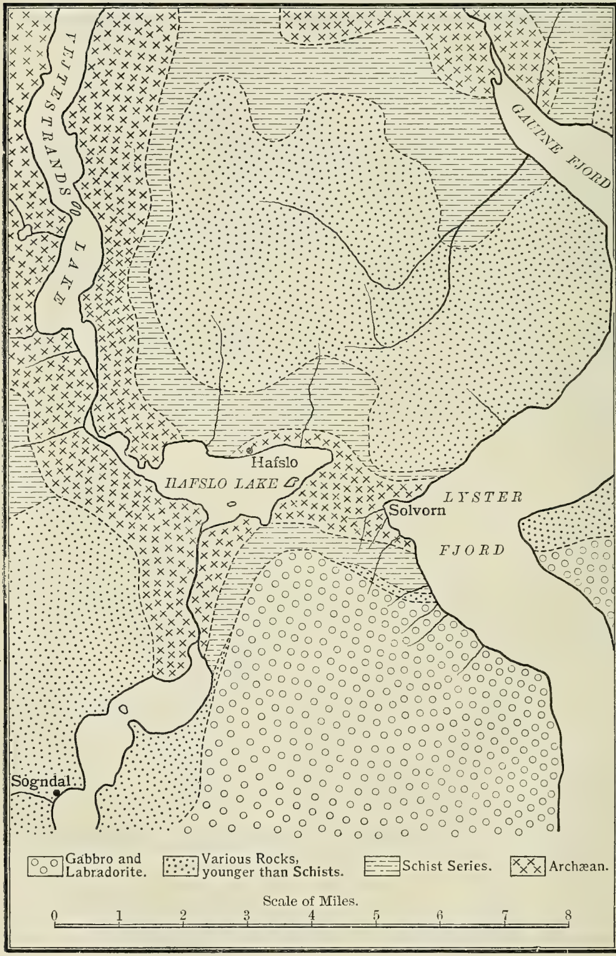
If we look at Dr. Björlykke's map, we shall see a great mass of igneous rock marked at the head of the Sogne Fjord with a diagonal boundary running north-east and south-west. Along this boundary there is a narrow belt of Silurian and associated strata, dividing the igneous rock from a vast area of Archæan gneiss, etc., which extends outwards from it to the western coast. On the Archæan area is a great plateau covered with perpetual snow, Jostedalsbræen, associated with many smaller snow-covered plateaux; and they have also a north-eastern and south-western trend, parallel with the Silurian belt at a distance of some 18 miles.

On the south-eastern side of the snowfields we find a series of valleys with a tendency to run in a south-easterly direction at right angles to the Silurian belt. They are Mörkereidsdal, Jostedal, the valley of the Vejtestrands Lake, and Sogndal. Then we find other valleys running at right angles to the above, and parallel with the Silurian belt: they are the upper part of the Lyster Fjord and the Sogndals Fjord with its allies.

The Hafslo Lake at once impresses one as being of interest, for it is placed at a point where two of these lines intersect, and I will briefly trace the course of its drainage-line from the snowfield; but first I would remark that the valleys in question are, in fact,

[1] Norges Geol. Undersök. No. 32 (1901) pp. 124 & 146–152.
[2] *Ibid.* No. 39 (1905). [3] *Ibid.* No. 47 (1908).

Fig. 1.—*Geological sketch-map of the neighbourhood of the Hafslo Lake and the Lyster Fjord.*



each a series of depressions or hollows, many of which are partly filled with water.

One of the larger Norwegian glaciers, Austerdalsbræ, descends from the great snowfield in a southerly direction into a deep valley, and other glaciers descend into a branch valley, Langedalen. Some 7 miles from the foot of Austerdalsbræ, we come to a lake, Vejtestrand, which has a length of nearly 11 miles. It is, however, almost divided by two small islands at a point 3 miles from its outlet.

The southern end of the lake is formed by a low barrier of rock which crosses the valley, a view of which is given in Pl. I, fig. 1, looking northwards: the lake being on the opposite side of the rock, which (it will be observed) is greatly rounded by ice. At one time there has been a flow of water over the western side of this barrier (left side of the view); but now the outlet from the Vejtestrands Lake is through a deep and narrow gorge cut in the rock and seen in the centre of the view. Near its lower end the road from Hafslo crosses the gorge by a bridge shown in the view, and the river flows out on the left into the sheet of water seen in the foreground.

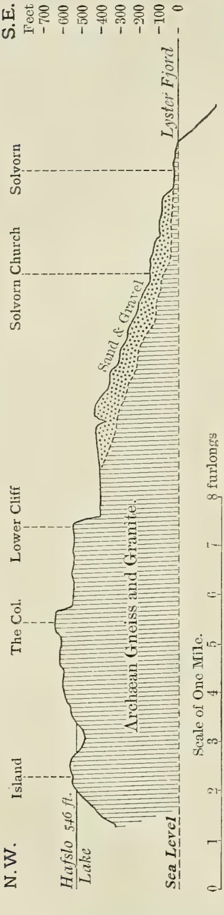
Fig. 2 in Pl. I is a view of the gorge taken from a point on the rock-barrier above the bridge just mentioned, and nearer to the Vejtestrands Lake, a part of which is seen in the distance. A large kettle-hole will be noticed on the western side of the gorge, and also a track, much out of repair, made for the use of fishermen, which gives an idea of the scale. I would point out that this gorge, with its large kettle-hole and other signs of great water-erosion, is at the outlet of a long lake; and I assume that much sand, gravel, or stones must have been used to assist the water in the erosion. Now, such material cannot have been brought down the lake by water alone; so I take it that the gorge must have been eroded when the lake was filled with ice, and probably by a river flowing under a glacier.

The length of the next section of the valley is nearly a mile and a half. It extends from the rock-barrier at the end of Vejtestrand to a conspicuous mound standing in the middle of the valley. The valley of the Vejtestrands Lake runs southwards, but in the section with which we are now dealing the valley shows a tendency to turn eastwards. On its northern side are steep cliffs of granitic gneiss, and the rock is greatly ice-worn: it has also been waterworn to a considerable height above the present water-level. In this rock we find a large giants' kettle, with a circular opening at its top. In the lower part of the kettle the rock is schistose, and there is a large hole through which one can enter the kettle. The present floor of the kettle is 12 feet below the lowest part of its lip; but, the bottom being filled with earth and stones, it may be much deeper. Internally the kettle measures 17 by 12 feet: its present floor is some height above the nearest water.

It should be noted that this waterworn rock and its giants' kettle are not in a gorge, but on the side of a valley half a mile

wide, the opposite flank of which is by no means precipitous; and I suggest that this waterworn rock and the kettle date from a time

Fig. 2.—*Diagrammatic section from the Hafslo Lake to the Lyster Fjord.*



when a glacier filled this part of the valley, and are due to a river which, in a more confined space than the present wide valley, either flowed through, or under the ice, or between it and the rock. On the side of the valley in which we find the giants' kettle there have been great post-Glacial landslips: masses of rock, angular and unwaterworn, now lying at the foot of the cliff and in the water before it. Possibly the glacier left this steep wall in an unstable condition, and when the ice melted it gave way.

It is possible that the part of the valley with which I am dealing may be a deep hollow in the rock; but, if so, it is largely filled with gravel and sand spread out like an alluvial flat and covered with peat, and, for the rest, the river which keeps to the western side of the valley for the most part, spreads out in places into sheets of water. Mounds of rock project here and there.

In any case, there is a great accumulation of material which must, I think, have come down the Vejtestrands Lake when it was occupied by a glacier; it is probable, indeed, that the foot of the ice stood for a time near the rock-barrier at the end of the lake, and that the alluvial flat is composed of moraine-material spread out by water in front of the ice.

The end of the section of the valley that we are now considering is, as I have said, a big mound which stands out in the middle of the valley. The river passes round the right side of the mound, and enters the Hafslo Lake. The mound, which is partly rock and partly moraine, joins the land on the left or northern side of the valley. I suggest that the glacier of which I have been speaking

halted here, and that we have a terminal moraine piled against the rock which forms the eastern end of this section of the valley.

The next hollow in the valley is that of the Hafslo Lake, which has a length of 3 miles, from west to east, and a breadth of 1 mile, from north to south. As I have said, the valley is now showing a tendency to turn eastwards; and in the mountains east of the lake there is a valley in continuity with that of the lake crossing the line of strike of the Silurian rocks and running out to the Lyster Fjord at Solvorn. As I shall show, there has formerly been a drainage from the lake in that direction; but the present outlet is in the middle of the southern shore of the lake, from which the water flows into a line of depressions parallel with the Silurian belt. (See the map, fig. 1, p. 20.)

At the outlet of the Hafslo Lake the rock is augen-gneiss. The road from Hillestad to Sogndal here crosses the river flowing out of the lake, and the rock on the left side has been cut in making the road; but on the right one can see waterworn rock rising to a considerable height above the present water-level, probably produced when the Hafslo Lake was filled by ice.

The lake is 546 feet above the sea, and the river from it reaches sea-level in less than 2 miles. The road follows the course of the river (the Aaroj), and the scenery is very fine. The river flows into a depression or hollow 2 miles long, named Barsnæs Fjord. It then passes into an almost circular depression which forms the topmost part of the Sogndals Fjord. At Sogndal we enter, through a narrow opening, the main part of the same fjord, which passes into the Norums Fjord, and then into the Nordnæs Sund opening into the Sogne Fjord 4 miles east of Lekanger. This opening into the Sogne Fjord is 14 miles from the Hafslo Lake, and the course for that distance may be said (speaking generally) to lie along the line of the Silurian belt; though, for the most part, the erosive agents have cut the valley down into the underlying gneiss.

Having now dealt with the existing line of drainage from the lake, I proceed to describe the disused line of drainage from the lake to the Lyster Fjord, which crosses the line of the Silurian belt at right angles; although the valley from the lake to Solvorn has been wholly cut down into the gneiss.

Fig. 2 (p. 22) is a diagrammatic section from the lake to Solvorn.[1] The eastern side of the Hafslo Lake is formed by a rock-barrier, in which there is a notch or col: this col is about 100 feet above the lake, and at the head of the Solvorn Valley. The rock is much rounded and iceworn, and if it be examined on the Solvorn side evidence will be found that a river flowing from the lake has passed over it. This is at the point where the Solvorn road leaves the Hillestad–Sogndal road.

[1] Dr. Reusch gives an ideal view of the locality in Norges Geol. Undersök. No. 32 (1901) p. 147.

If we look at the col from the Solvorn side, looking towards the lake, we see a high cliff with a flat marshy field at its foot. On the face of this cliff there are marks of the former existence of a large waterfall; but no water flows there now, nor can it do so again unless the ice should advance and once more fill the Hafslo Lake, up to at least the level of the col.

A little nearer Solvorn we come to another big step downwards (marked 'Lower Cliff' in fig. 2, p. 22), and here once more recur signs of a big waterfall. Again we see a flat at the foot of the cliff with fields and woodland; and I may mention that in one of the woods there is a small standing stone or bautasten, with other stones around it, a relic of early times.

The iceworn rock shows clearly that a glacier has flowed once or possibly often down this valley; but up to now we have seen very little moraine-material. We soon, however, find it in plenty; in fact, a vast mass of sand, gravel, and stones large and small occupies the lower part of the Solvorn Valley almost to the edge of the fjord. I suggest that the foot of the ice halted for a considerable time in the space between the 'Lower Cliff' and Solvorn (see fig. 2, p. 22) and that the sand and gravel, as well as some big boulders which are seen here and there, are in fact the terminal moraine of this glacier. This sand and gravel form a terrace, the surface of which is for the most part cultivated, and Solvorn Church and many houses stand upon it. It slopes rather steeply towards the fjord, with small level flats in places. The new road from Solvorn to Hafslo at first follows a rather deep valley, cut in this terrace by an existing stream which has a drainage-area independent of the Hafslo Lake, from which we are now at some distance. Half a mile from the fjord the road ascends the side of the rock-valley by a series of zigzags; and on the north of the road opposite these zigzags there is a pit in the terrace which affords a good section, showing sand and small gravel, well and evenly stratified, with a high dip towards the fjord. This stratification proves deposit in water which must have been the water of the fjord; and, if I am right in thinking that the terrace-deposit is a terminal moraine, the evidence shows that the foot of the ice rested here at a time when the sea stood at a level of at least the top of the terrace, estimated by Dr. Reusch as being 426 feet above the sea.

I know little to show the date of the rock-valleys of which I have been speaking, but am inclined to think that the Solvorn Valley, which belongs to the series at right angles to the Silurian belt, is probably older than the valley which runs from the Hafslo Lake to Sogndal, etc., along the line of the Silurian rocks. However that may be, it is clear that the moraine-material at Solvorn was brought across the Hafslo Lake by ice, and was placed in its present position at the time when the sea-level stood 426 feet higher than now.

The topmost marine limit shown by the terraces increases as we go inland from the mouth of the Sogne Fjord; that is, from west

Fig. 1. View of the rock-barrier at the southern end of the Vejtestrands Lake, looking northwards.

H. W. M., Photo.

Fig. 2. Gorge with big pothole at the southern end of the Vejtestrands Lake, looking northwards.

H. W. M., Photo.

Bemrose, Collo., Derby.

to east. In the map given by Dr. Rekstad[1] he marks the height as 328 feet a little to the west of Balestrand. In a later work[2] he places the late-glacial marine limit at 377 feet at Vik, on the south of the Sogne Fjord; and in another paper[3] he says that the highest terrace at Hovland on the Aardals Fjord (449 feet) apparently represents the highest marine limit after the Ice-Age. Hovland (Natviken) is 15 miles south-east of Solvorn, so this agrees very well with the 426-foot terrace at the latter place, and it clearly belongs to this late-glacial series.

This late date for the Solvorn terrace, together with other evidence, makes it difficult to believe that the outlet of the Hafslo Lake to Sogndal did not exist at the time of the deposition of the Solvorn moraine. Thus there is a series of ice-markings on the rock by the new road from Marifjæren to Hillestad, a little north of the latter place, and they point in a south-westerly direction: that is, towards the present outlet of the lake and not towards the Solvorn col. Moreover, there is evidence that a vast mass of ice passed down the series of fjords from Sogndal to the Sogne Fjord, for there are deep glacial groovings on Nordnæs, south of Norum Church.

I would suggest that, the Hafslo Lake being full of ice, the main glacier coming down the Vejtestrands Lake and a tributary down from the mountains north of Hillestad, and the main mass of ice moving down to Sogndal and the Sogne Fjord, there was an overflow of ice and water from the left side of the glacier over the Solvorn col and down towards that place. This view is supported by the presence of masses of moraine-material on the mountain-side above the shore of the Hafslo Lake, between the Solvorn col and the Sogndal outlet. There is no reason why more than one stream should not flow simultaneously from a single glacier; in fact, that is precisely what happens in the case of small recent glaciers, and the fact that the Solvorn col is 100 feet above the Sogndal outlet does not, I think, make a serious difficulty: for one river may have flowed in or over the ice, and the other beneath it. In any case, I think it more probable that both outlets were used during the late-glacial period and possibly simultaneously, than that the Sogndal outlet has been deepened as much as 100 feet since the deposition of the Solvorn mass of sand and gravel.

EXPLANATION OF PLATE I.

Fig. 1. View of the rock-barrier at the southern end of the Vejtestrands Lake, and of the gorge in it through which the river issuing from the lake flows; looking northwards.

2. Gorge, with a big pothole, at the southern end of the Vejtestrands Lake; looking northwards.

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[1] Bergens Museums Aarbog (1906) No. 1.

[2] Norges Geol. Undersök. No. 53 (1910).

[3] *Ibid.* No. 43 (1905) p. 43.

Discussion.

Dr. J. W. Evans congratulated the Author, not only on the excellence of the photographs that he had shown, but also on the clearness with which he had placed before his audience the problems in glacial geology presented by the district. The Author's suggestion that some of the lake-basins had been eroded by sub-glacial streams was similar to that brought forward by Werth to explain the formation of the depressions in morainic material. These depressions, which are now filled by the sea, are, according to Werth, known in Schleswig-Holstein as föhrden, in Sweden as fjärde, and in Denmark as fjorde, which are not to be confounded, of course, with the fiords of Western Norway. The traces of a former waterfall in the disused outlet appeared to the speaker to be such as would be caused by a merely temporary outflow in that direction.

Dr. A. P. Young thought that the possible action of waterfalls issuing from the glaciers themselves should be borne in mind, when considering the erosion which has taken place at the end of a glacier.

Mr. G. W. Young asked whether the Author considered the transverse or the longitudinal set of valleys to be the older, and also what were the causes that he suggested to account for the diversion of the drainage into its present course.

The Author, in reply, stated that those valleys which ran at right angles to the strike of the sedimentary rocks were the older, and that he attached greater importance to the action of water flowing under the ice than was usually attributed to it.

3. *The* TRILOBITE FAUNA *of the* COMLEY BRECCIA-BED (SHROPSHIRE). By EDGAR STERLING COBBOLD, F.G.S. (Read December 4th, 1912.)

[PLATES II & III.]

CONTENTS.

I. Introduction.

IN a report to the Dundee Meeting of the British Association (1912) upon the excavations made in the Cambrian rocks at Comley during 1911, I called attention to a *Paradoxides* fauna, which appears to be new to the district, and is found in the matrix of a remarkable breccia near Comley Brook.

The objects of the present paper are :—

(1) To figure the trilobites of this breccia-bed, and to describe those species which appear to be new ;

(2) To discuss the palæontological horizon in the Cambrian System which they indicate ; and

(3) To consider some inferences that may be drawn from the occurrence of this fauna in its present position among the rocks of Comley.

II. Recapitulation of Previous Observations.

In order to make clear the special significance of the fossiliferous Breccia-Bed, it is necessary to recapitulate some of the observations already published.

In the section of the Quarry Ridge,[1] the *Groomii* Fauna is found in the matrix of a conglomeratic grit which rests upon the Lower Cambrian limestones that yield the *Protolenus-Callavia* Fauna.[2]

A similar conglomeratic grit is found at Robin's Tump[3] with some of the same fossils; but in this case it rests, with visible unconformity, on bedded green sandstones, which are regarded as lower in the Cambrian sequence than the *Protolenus-Callavia* Limestones.

The conglomeratic nature of the grit is easily recognized, for the matrix consists largely of rounded quartz-grains with a liberal sprinkling of glauconite, and the included blocks are either pieces

[1] Rep. Brit. Assoc. 1908 (Dublin) 1909, pp. 234, 236: Excavations Nos. 1 & 2.

[2] E. S. Cobbold, Q. J. G. S. vol. lxvii (1911) p. 297.

[3] Rep. Brit. Assoc. 1910 (Sheffield) 1911, p. 117 ; *ibid.* 1911 (Portsmouth) 1912, p. 111 & fig. 1, p. 112.

of green sandstone of much finer grain or of limestone containing fossils of the *Protolenus-Callavia* Fauna.

In most cases these fossils belong to the *Bellimarginatus* group of that fauna, although sometimes they may belong to the *Helena* group.[1]

At a point near Comley Brook,[2] within 300 yards of the Quarry Ridge, the Breccia-Bed, the trilobites of which are described in the present paper, rests upon solid and regularly-bedded green sandstones of the Lower Cambrian.

The breccia is composed of blocks and chips of green sandtone (both fossiliferous and barren) and of pinkish limestone, the fossils including many of the species of the '*Helena* group' of the *Protolenus-Callavia* Fauna, and, apparently, of no other group. The matrix of this breccia consists of comminuted fragments of the same materials, and has consolidated to a green sandstone of very much the same aspect as the parent rock. This matrix varies a little from point to point in the bed, in places becoming somewhat coarser and having some admixture of quartz-grains, in other places becoming more calcareous and sometimes fine-grained.

It is from this matrix that the new *Paradoxides* fauna has been collected.

Fortunately, before the Breccia-Bed was opened up, many fossils of the *Helena* group, embedded in a band of the Lower Cambrian green sandstones, had been found at Excavation No. 47 in the bed of Comley Brook,[3] and it is abundantly evident that the breccia is largely made up of fragments of these fossiliferous green sandstones.

Previously, the fossils of the *Helena* group had been found only in the well-known red *Olenellus* Limestone of Comley Quarry; now they have been found in the green sandstone, which forms the main body of the Lower Cambrian of the district, but there is no evidence available at present indicating to what depth below the *Olenellus* Limestone they descend.

The thickness of the Breccia-Bed is about 5 feet; it rests immediately upon the well-bedded Lower Comley green sandstone, without any sign of faulting along the surface of junction; its upper limit, however, is probably a faulted one. It is succeeded above by brownish shale, which apparently belongs to another horizon of the Middle Cambrian.

III. Description of the Trilobites.

Paradoxides Brongniart.

The matrix of the Breccia-Bed is plentifully charged with fragments of *Paradoxides*, which indicate an undescribed form, possessing characters in common with several well-known species.

[1] E. S. Cobbold, Q. J. G. S. vol. lxvii (1911) pp. 297, 298.
[2] Rep. Brit. Assoc. 1912 (Dundee) (in the press), Excavation No. 49.
[3] *Ibid.*

PARADOXIDES INTERMEDIUS, sp. nov. (Pl. II, figs. 1 *a*–1 *c*, 3 & (?) figs. 2, 4–11 *c*.)

Paradoxides cf. *hicksii* Salter & *sjögreni* Linnarsson, and *Paradoxides* cf. *rugulosus* Cobbold, Rep. Brit. Assoc. (Dundee) 1912.

The type-specimens are numbered [1828, 1832].[1]

CRANIDIUM: Pl. II, figs. 1, 3, and 4.

Dimensions in millimetres:—

Length	24
Width across anterior angles	28
Width across eye-lobes	29
Width across posterior angles	28
Length of chord of eye-lobe	10
Length of do. do. and ocular ridge together	$12\frac{1}{2}$

General form.—Quadrate, with deep notches in front of the eye-lobes.

General convexity.[2]—About 1 : 4.

Glabella.—Moderately convex; circularly rounded in front; widest at about a third of its own length from the front; narrowing to about two-thirds of this width at the occipital ring; with four pairs of furrows, of which the anterior is situated at the widest part and is short and rather indefinite, the second is somewhat longer (but also weak), the third is strong at the sides, but is rarely traceable across the axial line: all three pairs are disconnected from the axial furrow, while the fourth pair connects with it, is strong at the sides, and is continued across the axial line as an ill-defined shallow hollow.

Occipital furrow.—Straight and well-marked, except in the middle third, where it is somewhat ill-defined.

Occipital ring.—Wider in the middle than at the sides, so that the border projects strongly backwards.

Axial furrow.—Very little impressed.

Fixed cheeks.—Convex; highest near the glabella; marked diagonally, from the end of the occipital furrow towards the middle of the eye-lobe, by a change of curvature. This diagonal mark is seen in two specimens, but may be due to accidental damage before fossilization.

Eye-lobe and ocular ridge.—Long and wide; extending from the postero-lateral furrow to the glabella; gently convex; separated from the fixed cheek by a distinct but lightly-impressed line.

Postero-lateral border.—Furrow narrow, straight, and but little impressed; marginal fold wide and gently convex.

Front.—A gently convex fold curves round the front of the glabella, and is separated from it by a shallow groove; both become gradually less marked as they are followed towards the facial suture,

[1] The numbers in square brackets are those attached to the specimens in my collection for the Excavations Committee of the British Association.

[2] That is, the ratio of the maximum height of the glabella to the maximum width of the shield.

where the fold increases to about double its original width; between this, the glabella, the facial suture, and the ocular ridge is a rhomboidal flat space.

Facial suture.—Anterior branch curving rapidly outwards from the eye-lobe to take a course almost exactly at right angles to the axial line, until it reaches the marginal fold: here it turns abruptly forwards, and passes to the front border parallel with the axial line. Posterior branch short, sigmoidal, and extending outwards to about the same distance as the eye-lobe.

Doublure.—In one specimen the upper part of the marginal fold is broken away, disclosing the cast of the doublure; it is as wide as the maximum width of the upper part of the fold, and is distinctly more convex.

Test.—The specimens on which this description is based are internal and external casts in sandstone that is too coarse to preserve any fine surface-markings. One or two fragments associated in the same rock, and probably belonging to the same species, have parts, at least, of the surface covered with fine granulations set well apart one from the other (see Pl. II, fig. 10 *c*, which, however, is taken from the axis of a pygidium). The doublure is furnished with a number of raised lines sub-parallel to the margin, and slight traces of similar lines have been detected on the upper part of the marginal fold.

The free cheek [1435] (Pl. II, fig. 2) and the hypostoma [1449] (fig. 5) were found in the same rock-bed; the latter is of the type of that of *P. bohemicus* Bœck and *P. tessini* Brongn., but seems proportionately narrower, and the border between the two posterior hooks is strongly curved. The width shown in the figure is necessarily an approximation.

Thorax: (?) Pl. II, figs. 6–8.

The thoracic segment (fig. 7) has unfortunately been broken up. It is remarkable for the narrowness of the axial portion in proportion to the spread of the pleuræ (it apparently occupies only a fifth of the total width), and also for the curved hook-like termination similar to that of *Paradoxides bohemicus* var. *salopiensis* Cobbold, from Neve's Castle.

The fragment [1455] fig. 8 appears to be part of one of the most posterior pleuræ.

Pygidium: (?) Pl. II, figs. 9–11.—Up to the present only one form of pygidium has been found in the same rock-bed as that which has yielded the cranidia; there is little doubt that it belongs to the same species. It varies a little in contour, but is always nearly circular. In general form it is like that of *P. hicksii* from South Wales, but shows only one feebly-marked annulation of the axis (apart from the articulating facet). Linnarsson's figure of the pygidium of *P. sjögreni* is very like the Comley form, but it is more quadrate.

The surface-characters, shown in one specimen [1443], consist of very fine raised lines near the border (fig. 10 *d*) and minute granules standing well apart one from the other on the axial lobe (fig. 10 *c*).

Comparisons with other Species.

Paradoxides intermedius simulates the three forms *P. hicksii*, its variety *palpebrosus* Linnarsson, and *P. sjögreni*, in the weakness of the glabellar furrows along the axial line, but differs in the course of the facial suture, and consequently in the general form of the cranidium, and also in the outline of the glabella.

In both these characters and in the length of the eye-lobe it approaches *P. rugulosus* and the American allies of that species: namely, *P. eteminicus* Matthew and *P. acadicus* Matthew; but the transverse course of the facial suture and the obsolescence of the glabellar furrows on the middle line at once differentiate it, as also does the shape of the pygidium, if the examples figured really belong to the same species as the cranidia.

The proximity of Excavation No. 49 to Comley Quarry, where *P. groomii* Lapworth is found, and the proportion of 1 : 5 that obtains equally in the thoracic segment assigned [1] to that species and in the segment now figured (Pl. II, fig. 7), necessitate a comparison between the two species. Both have glabellar grooves that are weak and almost evanescent on the axial lines, and the domes of the glabellas were probably of the same rounded form; but *P. groomii* of the Quarry is much larger, it has a very markedly smooth test, a wider hypostoma with the posterior border straight for the greater part of its length, and a very characteristic nether surface to the free cheek. Fragments of this characteristic surface are abundant in the fossiliferous clots of the Quarry-Ridge Grits, and it would indeed be remarkable that they should be absent from the Breccia-Bed, if the two species were identical.

The form which I have figured [2] as *Paradoxides* sp. indet. No. 2 resembles *P. intermedius* in the long and wide eye-lobe, and in the short posterior branch of the facial suture; the surface-characters of the pygidia are akin though not identical, but their external forms are quite different.

Locality and horizon.—Excavation No. 49, near Comley Brook: from the matrix of the Breccia-Bed.

Agraulos Corda.

Agraulos sp., cf. Arionellus quadrangularis Whitfield. (Pl. II, figs. 15 *a*–15 *c*.)

R. P. Whitfield, Bull. Amer. Mus. Nat. Hist. vol. i (1881–86) p. 147 & pl. xiv, fig. 8.
C. D. Walcott, U.S. Geol. Surv. Bull. No. 10 (1884) p. 48 & pl. vii, fig. 1.
A. W. Grabau, Occasional Papers, Boston Soc. Nat. Hist. vol. i (1900) No. 4, pt. 3, p. 674, pl. xxxiv, figs. 9–10 & pl. xxxv, fig. 1.
E. S. Cobbold, Q. J. G. S. vol. lxvii (1911) p. 292, pl. xxv, figs. 13, 14, & ? 15.

Two fragmentary specimens [1395, 1397] are very like the form figured [3] from the *Davidis* Zone of Comley.

[1] E. S. Cobbold, Q. J. G. S. vol. lxvii (1911) p. 284 & pl. xxiii, fig. 6.
[2] *Id. ibid.* pl. xxiv, figs. 3–6.
[3] *Id. ibid.* pl. xxv, figs. 13, 14, & ? 15.

Subgenus **Strenuella** Matthew ?

AGRAULOS (STRENUELLA ?), spp. indet. (Pl. II, figs. 12 *a*–14 *c*.)

Several fragments of cranidia [1398, 1847, 1878 *c*], with strongly-marked features, a large and prominent glabella, but with only a medium-sized eye-lobe, suggest a reference to Matthew's subgenus ; in two specimens a strong nuchal spine, projecting horizontally backwards, may be noted.

Conocoryphe Corda.

Subgenus **Conocoryphe**, *sensu stricto*, Grönwall, 1902.

CONOCORYPHE (C.) ÆQUALIS Linnarsson. (Pl. III, figs. 18 *a*–18 *c*.)

G. Linnarsson, Sver. Geol. Undersökn. ser. C, No. 54 (1883) p. 25 & pl. iv, figs. 12–15.
K. A. Grönwall, Danmarks Geol. Undersög. ser. 2, No. 13 (1902) p. 92 & pl. i, fig. 22.

Six cranidia [1393, 1838, 1842, 1843, 1868, 1869] from the Breccia-Bed are apparently identical with Linnarsson's species.

They are in very close agreement with his figures and descriptions, but the matrix of the bed is too coarse to preserve any delicate markings on the surfaces of the casts.

In the specimen figured the missing parts, shown in outline, are restored from the external impression: but one pair of glabellar furrows is visible ; the 'ocular ridge' is faintly traceable for a short distance only across the cheek ; and in the view from above the facial sutures appear to be nearly straight.

The convexity ratio is 1 : 3·7.

CONOCORYPHE (C.) BUFO Hicks. (Pl. III, figs. 17 *a*–17 *c*.)

1865. J. W. Salter, Rep. Brit. Assoc. (Birmingham) p. 285.
1868. J. W. Salter & H. Hicks, Q. J. G. S. vol. xxv (1869) p. 52 & pl. ii, fig. 8.

Four specimens of cranidia [1388, 1391, 1844, 1845] from the Breccia-Bed are referable to this species. They are preserved as internal and external casts, but the latter are the more fragmentary. One specimen [1391] is so much distorted that its proportions cannot be made out ; but the external cast is valuable, as giving indications that the surface was strongly granular or tuberculate. The figured specimen [1388], which is practically complete, differs a little from the type as described and figured by Hicks. It has a proportionately larger and less tapering glabella, the triangular boss of the anterior margin does not reach so far back, and the glabellar furrows are not very clearly marked.

The length of the head-shield is about 13 millimetres and the convexity ratio is about 1 : 4. Other specimens measure 10 and 4·5 mm. in length of head-shield.

The shield figured in Pl. III has suffered a curious distortion before fossilization, parts of the left cheek and posterior margin

having been sharply buckled, but without actual fracture. A somewhat similar distortion is indicated in Linnarsson's figure of *Conocoryphe exsulans*.[1] In both instances the test appears to have possessed a considerable amount of flexibility.

Subgenus **Liocephalus** Grönwall, 1902.

CONOCORYPHE (L.) IMPRESSA Linnarsson. (Pl. III, figs. 16 *a*–16 *c*.)

1879. G. Linnarsson, Sver. Geol. Undersökn. ser. C, No. 35, p. 20 & pl. ii, figs. 29–30.
1902. K. A. Grönwall, Danmarks Geol. Undersög. ser. 2, No. 13, p. 101 & pl. i, fig. 25.

A single cranidium, which is practically complete [1384], is closely in agreement with Linnarsson's description and figure, and may confidently be referred to his species from the *Exsulans* Limestone of Andrarum.

The specimen is preserved as an internal cast, with portions of the test adhering. There are very faint traces of the ocular ridge and the associated radiating lines, but no indication of the oval tubercle on the line of the axial furrow, which is mentioned by Linnarsson; otherwise his description applies well to the Comley specimen. Its convexity ratio is about 1 : 4.

Linnarsson compares his species with *C. lyelli* Hicks[2] (as figured, not as described). The South Wales species has, apparently, very distinct glabellar furrows and a strongly-marked ocular ridge; in these respects it differs from the Comley specimen.

The form *C. emarginata* var. *longifrons*[3] seems to be somewhat intermediate in character between the Comley form of *C. impressa* and the Swedish *C. emarginata* Linnarsson.

The specimen in question is one of the few Middle Cambrian fossils from Comley that are in a state of preservation similar to that of the majority of fragments of the Lower Cambrian *Callavia* and its associates. The test is partly weathered to a soft chalky-white substance that is easily removed, although in the portions lying deeper in the rock-fragment it is sufficiently hard to preserve the surface-characters.

Dorypyge Dames.

DORYPYGE RETICULATA, sp. nov. (Pl. III, figs. 1 *a*–15.)

Dorypyge sp. with reticulate test, Cobbold, Rep. Brit. Assoc. 1912 (Dundee).

Some twenty head-shields and seventeen pygidia from the Breccia-Bed, with four hypostomas, form the material to hand illustrating this species.

The specimens taken as the types are as follows :—

Cranidia [1407, 1411, 1882, and 1886]; hypostomas [1535, 1812, and 1814]; pleuræ [1419 and 1472]; pygidia [1434, 1472, 1819, and 1819 *a*].

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[1] Sver. Geol. Undersökn. ser. C, No. 35 (1879) pl. ii, fig. 21.
[2] H. Hicks, Q. J. G. S. vol. xxvii (1871) pl. xvi, figs. 1–7.
[3] E. S. Cobbold, Q. J. G. S. vol. lxvii (1911) p. 286 & pl. xxiv, figs. 8–13.

CRANIDIUM: General form.—Irregularly pentagonal, with the front angle rounded, the base somewhat three-lobed, and the sides contiguous to it a little irregular.

General convexity.—In the smaller specimen [1886] (fig. 3) the ratio is 1 : 2·7.

Size.—Varying from 2·5 to 20 millimetres in length.

DIMENSIONS OF THREE SPECIMENS IN MILLIMETRES.

Number of specimen	[1407]	[1411]	[1886]
Length, omitting the spine	19	ca. 15	6
Width across posterior angles	28	ca. 22	8·5
Width across eye-lobes	23	ca. 19	7·5
Width across anterior angles	22	ca. 17	6·5

A comparison of these three sets of measurements proves that the crushed specimen [1407] has given way vertically, and has not been materially widened by pressure, except possibly at the anterior angles.

Glabella.—Strongly convex; highest at about the middle of its length, widest at a point somewhat in advance of this; with sides nearly straight posteriorly; apex well rounded and reaching the front marginal fold; without actual furrows, but their positions are indicated by the absence of rugosities on the exterior (see p. 35).

Occipital furrow.—Wide and rather deep.

Occipital ring.—About an eighth of the length of the shield, exclusive of the spine; armed with a rather short spine rising from the upper surface of the ring, and directed upwards and backwards. The specimen [1882] (Pl. III, fig. 2), from which the spine came away during development, shows the impression of the doublure or nether side of the ring.

Axial furrow.—Very strongly marked in the internal casts [1407, 1886] (Pl. III, figs. 1 & 3); but narrow and only slightly impressed on the exterior [1411] (fig. 5).

Fixed cheek.—Trapezoidal; about half as wide as the glabella at a point opposite to the eye-lobe; highest close to the axial furrow; moderately convex towards the eye-lobe, strongly convex both forwards and backwards.

Ocular ridge.—Absent.

Eye-lobe.—Situated so that the anterior end is opposite the middle of the length of the cranidium; about a quarter as long as the glabella; with a depressed crescentic area and a decidedly raised and rounded margin (Pl. III, fig. 5).

Postero-lateral border.—Consisting of a strong marginal fold and a wide groove, both of which lose force towards the facial suture; strongly convex downwards, almost geniculate, from a

point about two-thirds out from the glabella; extended laterally to a greater distance than the eye-lobe.

Front.—Rounded at the apex of the glabella, but almost straight from it to the sutures; consisting of a narrow marginal fold, separated from the glabella and cheeks by a sharp and narrow groove; towards the sutures both fold and groove widen and tend to die away.

Facial suture.—Anterior branch, as seen from above, almost parallel to the axial line, but curved inwards at its termination to join the anterior margin tangentially. Posterior branch strongly divergent, but also curving inwards at its termination to join the posterior margin tangentially.

Free cheek.—When attached to the cranidium, the free cheek would be foreshortened in width, and show but a small area in the view from above (Pl. III, fig. 1 *a*); but, as seen lying in the rock (figs. 6 & 7), it is nearly as wide, opposite the eye, as the fixed cheek. It consists of two parts sub-equal in width: (i) an inner convex area concentric with the eye, and (ii) a wide, convex marginal fold, which is the continuation in an expanded condition of the front marginal fold of the cranidium; the two parts of the free cheek are separated by a wide but ill-defined hollow, which connects the anterior and posterior marginal grooves of the cranidium; the genal angle is produced to form a rather short spine, about half the length of the outer border of the cheek; in consequence of the curved course of the posterior termination of the facial suture, a sharp point is left on the cheek between the suture and the base of the spine.

Test.—The surfaces of the glabella and cheeks are covered with a bold pattern of reticulate, raised lines, beautifully shown in the specimens retaining the test [1882, 1411] (Pl. III, figs. 2 & 5). No trace of this is seen on the internal casts, but on the external casts the same pattern is often traceable as a network of impressed lines, enclosing roughly hexagonal, or rounded prominences (fig. 1 *c*). On the sides of the glabella the reticulations tend to become parallel with its margin, and are interrupted at the places where the glabellar furrows might be expected to occur (fig. 2). On the marginal fold the reticulations are elongated, and give rise to a system of anastomosing raised lines (fig. 5).

The furrows appear to be smooth.

Hypostoma (Pl. III, figs. 8, 9 *a*, & 9 *b*).—Four fragmentary examples of hypostomas from the same rock-bed may be referred to this species [1535, 1812, 1813 and 1816, 1814 and 1815].

In general form the hypostoma is rather closely comparable to that of *Olenoides ellsi* Walcott[1]; but the points of the wings are set farther back.

The body of the hypostoma is very convex and of an elongated oval form, about twice as long as wide, and a little narrower

[1] 10th Ann. Rep. U.S. Geol. Surv. 1888–89 (1890) pp. 643, 644 & text-fig. 66 *g*.

posteriorly than anteriorly[1]; the oval is surrounded by a convex border, which expands at the sides into pointed and somewhat flattened wings. The width across the points is nearly or quite as great as the total length of the hypostoma.

The border is traceable forwards as a narrow rim reaching the anterior end, where it appears, from the specimens, to be bent upwards at the margin.

The postero-lateral angles are damaged in all the specimens: it is, therefore, impossible to say whether they were furnished with hooks. About half-way between these angles and the points of the wings there is a little projection on each side.

The convex body is covered with a close-set network of raised lines, which are modified on the border and wings to linear rugosities, parallel to the margins.

No maculæ have been detected, nor any division of the convex body, such as is shown and described by Walcott for *Olenoides ellsi*.

THORAX (Pl. III, figs. 10–12 & 15).—Only detached pleuræ, and one complete but small thoracic segment, have been found.

Axis.—Convex, probably spinose, or having a pointed node.

Pleuræ.—Short and wide; abruptly bent downwards about half-way out; with a wide groove and strong anterior and posterior ribs; the anterior rib is prolonged to form a short rounded spine, which is directed rather strongly backwards; the posterior rib curves forward at its termination to join the anterior at the base of the spine. The spines of some pleuræ (the anterior?) are shorter than those of others; in front of the outer part of the anterior rib there is a flattened shoulder-like expansion, or facet for enrolment.

PYGIDIUM (Pl. III, figs. 13–15).—The pygidia vary much in size, one being but 2·5 millimetres long, others measure 4 to 5 mm., and yet other fragments indicate a length of 16 mm.

General form.—Approaching a semicircle; convex: the convexity ratio of one small specimen being about 1 : 4.

Axial lobe.—Very convex; about a third of the total width of the shield anteriorly, but tapering backwards to the rounded extremity; reaching to the inner margin of the border; divided by six[2] grooves into—the anterior articulating facet, four subequal divisions, one shorter division, and the somewhat bulbous and rather longer terminal division; the last groove is much less distinct than the others; the descent to the border is but moderately steep; there are no spines or nodes on any of the divisions.

Lateral lobes.—Sub-triangular; moderately convex; marked by four distinct furrows, with intermediate flattened ribs between them; sometimes there are traces of fifth and sixth furrows posterior to these; the anterior rib is narrow and well rounded, and is traceable across the border.

Border.—Continuous round the sides and end of the pygidium;

[1] The terms anterior and posterior are used here in accordance with the actual position of the plate when attached to the head-shield.

[2] In the restoration (Pl. III, fig. 13) one of these grooves has been omitted.

flat, and having a width equal to about a seventh of the length of the shield, omitting the spines; armed on each side with six spines, which are somewhat hooked at their terminations, and decrease in size from front to rear; in front of the anterior rib of the lateral lobe where it crosses the border there is a shoulder-like expansion or facet; posteriorly, and immediately upon the axial line, the border is crossed in the smaller specimen (Pl. III, fig. 15) by a slightly raised riblet, a very faint trace of which is also to be detected on the largest [1819] (fig. 13).

Test.—No specimen of the pygidium is sufficiently well preserved to show the surface-characters.

The species differs from the other form of the genus from Comley (*Dorypyge lakei* Cobbold)[1]: (1) in having a rather longer eye-lobe; (2) in being proportionately wider across the posterior angles of the cranidium; (3) in the surface-characters; (4) in the proportionate length of the spines; (5) in the presence of pleural facets, no traces of which have been detected in *D. lakei*; (6) in the more tapering axis of the pygidium; (7) in the absence of spines on that axis; and (8) in the diminution backwards in the length of the marginal spines.

No trace of a pit on the line of the axial furrow, such as that which is so noticeable in *D. lakei*, has been detected in *D. reticulata*.

The cranidia of the two species are very much alike, but the thorax and pygidia are decidedly different, and the reticulate character of the test, when it can be observed, is very distinctive.

Microdiscus.

MICRODISCUS PUNCTATUS Salter.

J. W. Salter, Q. J. G. S. vol. xx (1864) p. 237 & pl. xiii, fig. 11.
P. Lake, 'British Cambrian Trilobites' Monogr. Pal. Soc. vol. lxi (1907) pt. 2, p. 36 (where full references are given) & pl. iii, figs. 11–17.

Of this form, only one specimen has been found [1471] in the Breccia-Bed. It consists of the concave interior of a cranidium, with some of the calcareous rock-matrix adherent in places. Those portions of the interior of the test which are clear of this matrix show distinctly a regular series of punctations, apparently deep enough to pass quite through the test. Mr. Philip Lake, who kindly examined the specimen, observes (*in litt.*) that

'the crenulation of the margin does not look so fine and regular as is usual in *M. punctatus*. But possibly the nature of the matrix may have something to do with the difference in the appearance.'

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[1] Q. J. G. S. vol. lxvii (1911) p. 287 & pl. xxv, figs. 1–8.

Ptychoparia Corda.

Subgenus **Liostracus** Angelin.

PTYCHOPARIA (LIOSTRACUS) LATA, sp. nov. (Pl. II, figs. 16 *a*–17 *c*.)

Ptychoparia (Liostracus), sp. allied to *Pt. (L.) pulchella* Cobbold, Rep. Brit. Assoc. 1912 (Dundee).

Of the seven or eight casts of cranidia in the collection from the Breccia-Bed the internal cast [1403] is selected as the type for the species. It is the only one that seems to retain the natural convexity without distortion.

CRANIDIUM: General form.—Trapezoidal, with front well rounded, so as to be a segment of a circle; features in strong relief.

Size.—Length, exclusive of occipital spine, = 8 mm.; width across eye-lobe = 10 millimetres.

General convexity.—Considerable; ratio, about 1 : 3·2.

Glabella.—Convex and wide; tapering slightly forwards; apex bluntly rounded; bent down strongly forwards; highest in the posterior third of the length; widest at the base, where it is very little less than the length; two pairs of the lateral furrows are just discernible on the internal cast.

Occipital furrow.—Wide and well-marked; a little shallower in the middle than at the sides.

Occipital ring.—Almost entirely merged in the base of a strong, but rather short, spine, which projects upwards to a height distinctly greater than that of the glabella, and backwards to a distance from the occipital furrow a little more than half the length of the glabella.

Axial furrow.—Continuous round the sides and apex of the glabella; wide and well-marked, but not deep, except when the head-shield has been compressed vertically.

Fixed cheeks.—Scarcely half the width of the glabella; gently convex in the middle; descending steeply to the eye-lobe and towards the postero-lateral furrow, but more gently forwards; continuous by a narrow convex space round the apex of the glabella; highest opposite the posterior third of the glabella.

Eye-lobe.—Convex and raised as compared with the slope of the cheek, from which it is separated by a distinct groove; situated about half-way along the course of the facial suture, and having a length approximately equal to half that of the glabella.

Postero-lateral border.—A rather flat fold, widening a little outwards; separated from the fixed cheek by a wide and shallow furrow, with which the occipital furrow makes one straight line across the head-shield.

Front.—Extending forwards for a distance nearly equal to half the length of the glabella, and consisting of three sub-equal parts: (1) a convex space, connecting the fixed cheeks; (2) a shallow hollow; and (3) a convex marginal fold.

Facial suture.—Slightly convergent in front of the eye, more strongly divergent behind it.

Test.—The external casts invariably show a granular surface; but, as this varies in agreement with the coarseness or fineness of the matrix, it is probable that the external surface of the cranidium was smooth.

This form has many points in common with *Ptychoparia (Liostracus) pulchella* from the *Davidis* Fauna at Comley. It differs, however, in the greater width of the glabella, the concurrent narrowness of the fixed cheeks, the absence of the ocular ridge, and in the shorter and more erect occipital spine. Also the eye-lobe appears to be somewhat larger and situated rather more forward.

Through the above-mentioned species, *Pt. (L.) lata* is related to *Pt. (L.) valida* Matthew and *Pt. (L.) linnarssoni* Brögger.

PTYCHOPARIA (L.) ? DUBIA Cobbold. (Pl. III, figs. 19 *a* & 19 *b*.)

Q. J. G. S. vol. lxvii (1911) p. 295 & pl. xxv, figs. 19–21.

Two small cranidia from the Breccia-Bed agree with this species, so far as they go. It is obviously quite possible, however, that they are immature individuals of the form *Pt. (L.) lata.*

IV. The Stratigraphical Horizon of the Breccia-Bed.

So many of the trilobites are either indifferently preserved, or belong to species hitherto undescribed, that any correlation of the Breccia-Bed with a well-defined Cambrian horizon elsewhere must be somewhat hypothetical.

The two Welsh species, *Conocoryphe bufo* Hicks and *Microdiscus punctatus* Salter, are quoted from the Menevian of St. David's, the former from the grey beds at the base of the group.[1]

M. punctatus is also found in Scandinavia, but was described by Linnarsson under the two names *M. scanicus* and *M. eucentrus*.[2] Both at Andrarum[3] and at Bornholm[4] it occurs in the *P.-tessini* Zone, and also, at the latter locality, in the *P.-davidis* Zone.

Conocoryphe æqualis Linnarsson marks a definite sub-zone near the top of the Scandinavian *P.-tessini* Beds, while *C. impressa* Linnarsson occurs in the lowest sub-zone of the same group. The two species are found at Andrarum (Moberg, *op. cit.*) and at Bornholm (Grönwall, *op. cit.* pp. 92, 101, & 168) in the same relative positions.

[1] J. W. Salter & H. Hicks, Q. J. G. S. vol. xxv (1869) p. 53.

[2] P. Lake, 'Brit. Camb. Trilob.' Monogr. Palæont. Soc. vol. lxi (1907) pt. 2, p. 36.

[3] J. C. Moberg, Geol. Fören. Stockholm Förhandl. vol. xxxii (1910) pt. 1, pp. 57–59.

[4] K. A. Grönwall, Danmarks Geol. Undersög. ser. 2, No. 13 (1902) pp. 79–81 & 167.

Ptychoparia (Liostracus) lata appears to be closely related to *Liostracus linnarssoni* Brögger, which is found at Andrarum and Bornholm throughout the same *Tessini* Zone.

The two forms *Pt. (L.) dubia* and *Agraulos* cf. *quadrangularis* are rather poorly preserved, but appear to be the same forms as those quoted from the *Davidis* Fauna of the Shoot-Rough-Road beds of Comley.

A comparison of the fauna of the matrix of the Breccia-Bed with that of the Quarry-Ridge Grits shows a considerable contrast, the species of trilobites, so far as they are known, being all different.

TABLE ILLUSTRATING THE CONTRAST BETWEEN THE TRILOBITES OF THE *GROOMII* FAUNA AND THOSE OF THE BRECCIA-BED.

Genera.	Species recognized up to the present.	
	From the Quarry-Ridge Grits.	From the Breccia-Bed.
Paradoxides	*groomii* Lapworth[1]	*intermedius*, sp. nov.
Agraulos	None found	cf. *A. quadrangularis* (Whitfield).
Agraulos (Strenuella) ?	None found	Two species indeterminate.
Conocoryphe	*emarginata* Linnarsson, var. *longifrons* Cobbold	*æqualis* Linnarsson.
Conocoryphe	....	*bufo* Hicks.
Conocoryphe	....	*impressa* Linnarsson.
Dorypyge	*lakei* Cobbold	*reticulata*, sp. nov.
Microdiscus	None found	*punctatus* Salter.
Ptychoparia (Liostracus)	None found	*lata*, sp. nov.
Ptychoparia (Liostracus) ?	None found	*dubia* Cobbold ?

So far as they go, the species recognized indicate the presence at Comley of the *Paradoxides-tessini* Fauna, and it seems probable that the Breccia-Bed of Comley Brook represents part, if not the whole, of the *P.-tessini* Zone of Scandinavia. Further, it seems clear that the *Groomii* Fauna of the Quarry-Ridge Grits of Comley is quite distinct.

V. Inferences.

(1) Recalling to the reader's recollection the fact stated above that the fossils found in the component blocks of the Breccia-Bed belong to the *Helena* group of the *Protolenus-Callavia* Fauna, while

[1] Fragmentary remains indicate that there are two, or perhaps three, other species of *Paradoxides* which cannot at present be identified in the Quarry-Ridge Grits.

the matrix contains fossils of the *Tessini* Fauna, it would appear that, during the period represented by this latter fauna, a ridge of Lower Cambrian sandstones, from which the superincumbent Lower Cambrian limestones had been previously removed, was exposed to denudation, and that it was broken down, with little or no transportation of material, to form a sandy reef or shoal, which quite locally became a basal deposit of the Middle Cambrian.

(2) The fact that the *Groomii* Fauna of the Quarry-Ridge Grits (also a basal deposit) is quite distinct from the fauna of the Breccia-Bed, indicates that they are not contemporaneous, although both belong to Middle Cambrian time. We have, therefore, within the little district of Comley two basal deposits, separated in time by a sufficient interval to allow of a definite change of faunas.

(3) The exact horizon of the *Groomii* Fauna in the general Cambrian succession cannot at present be stated definitely, but that it is older than the fauna of the Breccia-Bed appears probable from three considerations:—(i) The *Conocoryphe* which it contains is allied to *C. emarginata* Linnarsson, which is, so far as known, confined to the *Œlandicus* Zone of Scandinavia.

(ii) The fauna of the Breccia-Bed is more nearly related to the *Davidis* Fauna of the Shoot-Rough-Road Beds of Comley than the *Groomii* Fauna seems to be.

(iii) The majority of the Lower Cambrian fossils found in the included blocks of the basal conglomerate of the Quarry-Ridge Grits belong to a somewhat higher horizon than those found in the component blocks of the Breccia-Bed; it may therefore be inferred that more time was required for the denuding forces to reach the parent rock of the latter, and the probability is that the Breccia-Bed is the younger of the two basal deposits.

VI. Conclusions.

The lithological resemblance between the matrix of the Breccia-Bed, yielding *Paradoxides*, and the beds of the Lower Cambrian sandstone, yielding *Olenellus* (*sensu lato*), is so close that, were it not for the presence of the fossils, it is doubtful whether I should have recognized its true nature. It was fortunate that this exposure was not discovered until after the local faunas of the Lower and Middle Cambrian had been fairly well established; for it is easy to imagine how collections made from this spot near Comley Brook might have been held to prove that *Paradoxides* and *Olenellus* were, in part at least, contemporaneous, in which case the Breccia-Bed would have been regarded as a passage-bed, where the two faunas overlapped.

In view of the fact that a reticulate surface to the test of trilobites has hitherto, so far as known, only been found among Lower Cambrian forms, special attention may be called to that seen in *Dorypyge reticulata*, sp. nov. The resemblance to some parts of the tests of *Callavia* from Comley is very close.

This reticulation is characteristic of the genera into which

Olenellus (*sensu lato*) has been recently divided by Dr. Walcott.[1] In only one species, *Olenellus argentus* Walcott, is it entirely replaced by another form of surface, a strongly granular one, and even this he regards[2] as but an extreme modification of original reticulation. Two other species, *Holmia rowei* Walcott[3] and *Wanneria gracilis* Walcott,[4] have a granular surface on parts of the test, but this is accompanied by a set of fine raised lines.

The same, or a very similar, reticulation is found in *Bathynotus holopyge* Hall, in *Conocoryphe (Atops) reticulata* Walcott, in a slightly modified form in *Avalonia manuelensis* Walcott, and in the Comley species *Mohicana clavata* Cobbold.

If this character of test is a primitive feature, it seems interesting to find it in a *Dorypyge* of Middle Cambrian age.

I cannot close this communication without expressing my indebtedness to Prof. J. C. Moberg, who very kindly sent me copies of the English translations of his Geological Guide to Andrarum, etc.[5] and of his 'Historical-Stratigraphical Review of the Silurian of Sweden,'[6] prepared on the occasion of the XIth International Geological Congress, 1910. They have been of great use, not only for the excellent bibliographies which they include, but also as giving a clear résumé of the work of previous authors.

I am also indebted to Prof. K. A. Grönwall for gifts of publications dealing with Swedish Cambrian horizons, and especially for his kindness in sending me a copy of his 'Bornholms *Paradoxides*lag' 1902.

To Prof. Charles Lapworth I am again greatly indebted for continued help and encouragement.

EXPLANATION OF PLATES II & III.

Plate II.

[All the figures are enlarged, except fig. 2, which is of the natural size.]

Paradoxides intermedius, sp. nov. (See pp. 29–31.)

Fig. 1. Internal cast of cranidium with left cheek flattened, and part of the external cast of the doublure visible on the right [1832]: *a*, view from above; *b*, side view; *c*, view from behind, with the convexity of the left cheek restored; all × 2.

2. Fragmentary free cheek of a much larger individual with test partly preserved [1435]: referred with doubt to the species; natural size.

3. Internal cast of cranidium [1828]: the left front and side are bent down, and buried in the rock; × 2.

4. Internal cast of fragmentary glabella [1440], referred with reserve to *P. rugulosus* Corda in Rep. Brit. Assoc. 1912 (Dundee).

5. Internal cast of fragmentary hypostoma [1449], with some portions restored from the counterpart [1450]; × 2.

6. Internal cast of termination of pleura [1454]; × 2.

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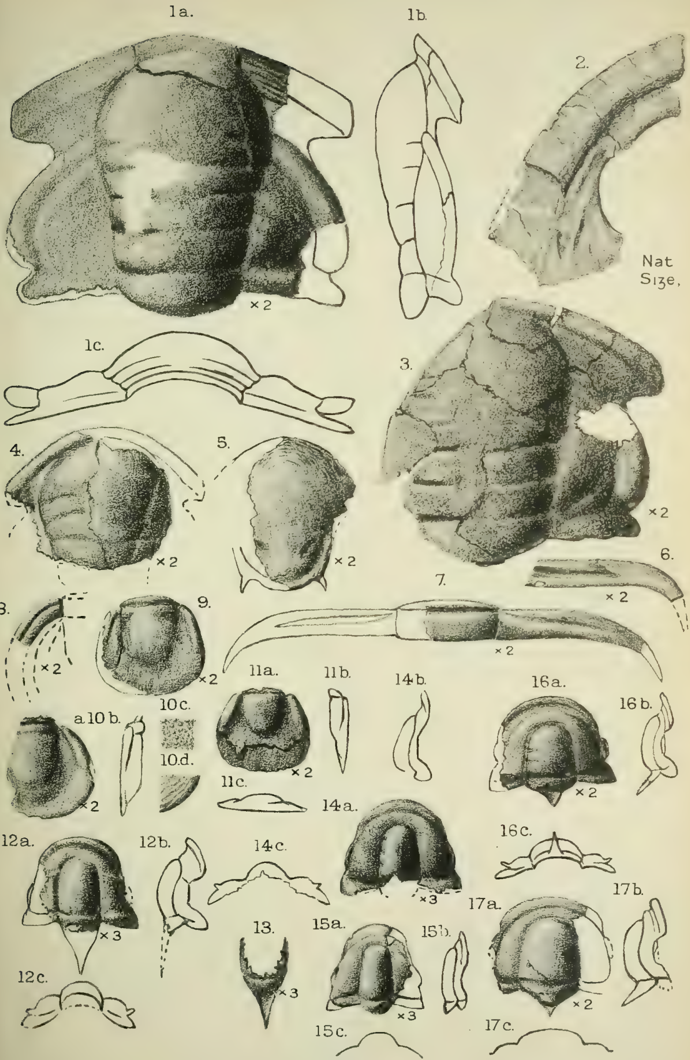
1 C. D. Walcott, Smithsonian Misc. Coll. vol. liii, no. 6, 1910.

2 *Ibid.* p. 315. 3 *Ibid.* p. 294. 4 *Ibid.* p. 299.

5 Geol. Fören. Stockholm Förhandl. vol. xxxii (1910) pt. 1, pp. 45–194.

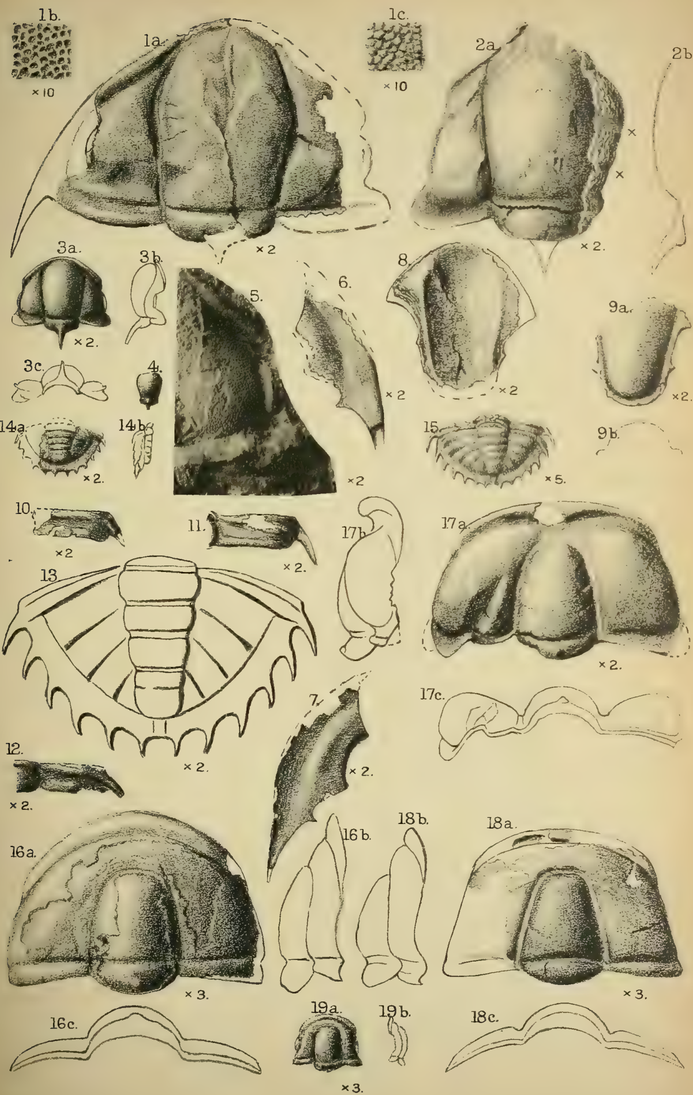
6 Sver. Geol. Undersökn. ser. C, No. 229 (1910).



E.S.C., Del.

Bemrose, Collo., Derby.

MIDDLE CAMBRIAN TRILOBITES FROM COMLEY (SHROPSHIRE).



E.S.C. Del. et Photo.

Bemrose, Collo., Derby.

MIDDLE CAMBRIAN TRILOBITES FROM COMLEY (SHROPSHIRE).

Fig. 7. Drawn from plasticine mould of part of an anterior thoracic segment; × 2; [specimen not preserved].
8. Fragment of a posterior pleura [1455], with the probable position of the pygidium indicated by dotted lines; × 2.
9. Internal cast of pygidium [1445]; × 2.
10. Exterior of pygidium [1443]: *a*, view from above; *b*, side view: both × 2; *c*, surface of axial lobe; *d*, surface of margin: both × about 7.
11. Internal cast of pygidium with a proportionately shorter axis, but probably belonging to the species [1817]: *a*, view from above, showing also the external cast of the wide doublure; *b*, side view; *c*, view from behind; all × 2.

Agraulos sp. indet. No. 1. (See p. 32.)

12. Internal cast of cranidium [1878 *c*]. The occipital spine, which is restored in outline, was destroyed during development of the fossil; it was in close agreement with that shown in fig. 13: *a*, view from above; *b*, side view; *c*, view from behind; all × 3.
13. Fragment of glabella and occipital spine [1398]; × 3.

Agraulos sp. indet. No. 2. (See p. 32.)

14. Internal cast of cranidium [1847]: *a*, view from above; *b*, side view; *c*, view from behind; all × 3. The three pairs of glabellar furrows, the contour of the glabella in the side view, and the absence of all trace of ocular ridge, differentiate this form from that shown in fig. 12.

Agraulos cf. *quadrangularis* (Whitfield). (See p. 31.)

15. Internal cast of cranidium [1395]: *a*, view from above; *b*, side view; *c*, section between the eye-lobes; all × 3.

Ptychoparia (Liostracus) lata, sp. nov. (See pp. 38–39.)

16. Internal cast of cranidium [1403], showing traces of two pairs of glabellar furrows: *a*, view from above; *b*, side view; *c*, view from behind; all × 2.
17. Internal cast of cranidium [1399] without glabellar furrows: *a*, view from above; *b*, side view; *c*, section between the eye-lobes; all × 2.

Plate III.

[All the figures are enlarged.]

Dorypyge reticulata, sp. nov. (See pp. 33–37.)

Fig. 1. Internal cast of cranidium [1407]: *a*, view from above, with free cheek restored in outline, × 2; *b*, part of the exterior of the test from specimen [1411], fig. 5, × 10; *c*, part of the external cast of the test [1408], which is the counterpart of [1407], × 10.
2. Partial internal cast of cranidium, with the test preserved on the right side of the glabella, where the rugosities are interrupted in two places marked X [1882]: *a*, view from above; *b*, longitudinal section; × 2.
The spine was destroyed during the development of the fossil, and the cast of the nether side of the occipital ring was then exposed.
3. Internal cast of cranidium [1886]: *a*, view from above; *b*, side view; *c*, view from behind; all × 2.
4. Glabella of the smallest individual found [1415]; × 2.
5. Photograph of exterior of fixed cheek and eye-lobe (with the postero-lateral margin pushed out of place by a vein of calcspar), showing, with a magnifier, the surface-characters [1411]; × 2.
6. Internal cast of free cheek [1410], as seen lying in the rock; × 2.
7. External cast of the same free cheek [1414]; × 2.

Fig. 8. External cast of hypostoma [1814]; × 2.

9. Internal cast of another hypostoma [1535]: *a*, convex view; *b*, cross-section; both × 2.

In both these hypostomas the posterior margin is defective, and consequently the presence or absence of spines or hooks at the posterior angles cannot be determined.

10. Anterior (?) pleura [1419]; × 2.

11. Posterior (?) pleura [1419]; × 2.

12. Posterior (?) pleura and part of axis [1817]; × 2.

13. Restoration of pygidium, chiefly from specimens [1819, 1819 *a*] which illustrate the size and almost all the characteristic features. One transverse groove has been accidentally omitted from the axial lobe in this figure.

14. Internal cast of part of pygidium [1434], which in point of size compares with the cranidium, fig. 3: *a*, view from above; *b*, side view; both × 2.

15. Minute pygidium, with one thoracic segment [1472]; × 5.

Conocoryphe impressa Linnarsson. (See p. 33.)

16. Cranidium with test partly preserved [1384]: *a*, view from above; *b*, side view; *c*, view from behind; all × 3.

Conocoryphe bufo Hicks. (See p. 32.)

17. Internal cast of cranidium, with left cheek buckled by unequal pressure [1388]: *a*, view from above; *b*, side view; *c*, view from behind; all × 2.

Conocoryphe æqualis Linnarsson. (See p. 32.)

18. Internal cast of cranidium [1393], with the missing parts restored in outline from the counterpart [1394]: *a*, view from above; *b*, side view; *c*, view from behind; all × 3.

Ptychoparia (Liostracus) ? dubia Cobbold. (See p. 39.)

19. Internal cast of cranidium, with occipital ring damaged [1457]: *a*, view from above; *b*, side view; both × 3.

[For the Discussion, see p. 49.]

4. Two Species *of PARADOXIDES from* Neve's Castle (Shropshire).

By Edgar Sterling Cobbold, F.G.S. (Read December 4th, 1912.)

[Plate IV.]

A number of trilobites, collected for H.M. Geological Survey by Mr. T. Rhodes in 1892 from Neve's Castle and Comley (Shropshire) have been submitted to me for study and identification by Prof. Charles Lapworth, under whose direction they were obtained.

Among these are two species of *Paradoxides,* from a dark flaggy limestone at Neve's Castle, that seem of special interest as representing forms well known elsewhere, but not hitherto noted from Shropshire.

The material available for description consists of a number of fragments of head-shields, several free cheeks and pleuræ, a few hypostomas and two pygidia. Almost every specimen has been subjected to a certain amount of distortion, and some have been crushed to a mosaic of small pieces, so that the natural convexity is lost. But the specimens are otherwise beautifully preserved: the tests, where unweathered, are intensely black, and show the delicate surface-characters excellently.

Paradoxides bohemicus Bœck, var. salopiensis, nov. (Pl. IV, figs. 6–17.)

J. de Barrande, 'Syst. Silur. Bohême' vol. i (1852) p. 367 & pl. x.

The fragments on which this variety is founded, taken together, indicate a close agreement with Barrande's description and figures, and with some Bohemian specimens which, through the kindness of the Keeper of the Geological Department of the British Museum (Natural History), I have had the opportunity of studying. There are, however, the following divergences, which are constant:—

(1) The eye-lobe is proportionately longer.

(2) The posterior branch of the facial suture is concurrently shorter, and its general course is less steeply inclined to the posterior border.

(3) The free cheek is proportionately shorter and wider, and has a slight intra-marginal ridge.

(4) The points of the pleuræ are more slender.

(5) The pygidium is more quadrate in outline, and has only two annulations on the axis apart from the articulating facet.

The cranidia figured (Pl. IV, figs. 6, 8, 9, & 12) are from 13 to 26 mm. long, and the eye-lobes are about half these lengths. In Bohemian specimens the proportion is more nearly a third. The front of the glabella is always truncately rounded, and has about twelve lines of discontinuous hair-like rugosities (figs. 10 & 11) near the anterior border. Similar rugosities are seen on some of the

Bohemian specimens, but are not mentioned in the description. Rather stronger rugosities are seen on the anterior border itself, and these creep over the margin on to the doublure in their course towards the facial suture.

The area of the free cheek (Pl. IV, fig. 7) is flat and wide, its lateral border is gently but decidedly convex, and parallel with it there is a slight rise in the surface forming the incipient intra-marginal ridge, which I have not seen indicated in any of the figures of the Bohemian specimens.

The pleuræ (Pl. IV, figs. 13 & 14) have a rather narrow groove, terminating subcentrally in the anterior portion of the thorax (fig. 13) and close to the posterior margin in the more posterior segments (fig. 14). The point, which is directed strongly backwards, is connected with the body of the pleura by a bold curve, and is decidedly slender. In Barrande's figures (*op. cit.* pl. x) the points are much wider.

The pygidia figured here (Pl. IV, figs. 15 & 16) are rather small; but, on comparison with Barrande's figure of the complete trilobite, are not smaller than might be expected to accompany the smaller cranidia (figs. 8 & 9). They both show a more quadrate outline than the Bohemian specimens, and have only two transverse furrows on the axis instead of three. Fig. 16 shows an approach to an oval form, but has fairly straight sides.

The hypostoma (Pl. IV, fig. 17) seems to be quite the same as the Bohemian form.

Test.—Apart from the rugosities already mentioned, the surface is smooth.

Comparison with the Allied Species.

In *P. tessini* Brongniart the front of the glabella is pointed, the glabellar furrows, though curved, are more direct; the length of the eye-lobe is less than a third of that of the head-shield; the posterior branch of the facial suture is relatively longer and inclined at a more acute angle to the margin; the pygidium is distinctly spatulate, being wider behind than in front, and it has three or four furrows across the axial lobe; the curve joining the body of the pleura to its point is of comparatively short radius. The Shropshire form approaches *P. tessini* in having the points of the pleura slender.

In *P. harlani* Green the front of the glabella is well rounded; the glabellar furrows are nearly direct; the length of the eye-lobe is less than a third of that of the head-shield; the facial suture behind the eye is relatively longer, and inclined more acutely to the margin; the pygidium is almost circular, and has but one furrow across the axial lobe; the pleural points are comparatively wide; and there is a tubercle on the occipital ring.

The cranidium of *P. abenacus* Matthew has a general form very similar to that of the Shropshire variety; the eye-lobe is as large or larger; the glabella is truncately rounded in front, and traversed

by two well-marked continuous furrows posteriorly, but has in addition two pairs of faint lateral furrows on the anterior portion; and there is a tubercle on the occipital ring.

Locality and horizon.—Neve's Castle (Shropshire), near the southern end of the Wrekin. Middle Cambrian.

PARADOXIDES HICKSI Salter. (Pl. IV, figs. 1–5.)

1865. J. W. Salter, Rep. Brit. Assoc. (Birmingham) p. 285.
1868. J. W. Salter & H. Hicks, Q. J. G. S. vol. xxv (1869) p. 55 & pl. iii, figs. 1–10.
1883. G. Linnarsson, Sver. Geol. Undersökn. ser. C, No. 54, p. 14 & pl. iii, figs. 1–5.

Five of the cranidia from Neve's Castle, with two free cheeks and a few other fragments, seem to indicate the presence of Salter's species in Shropshire; but the state of preservation of the specimens is very different from that of the specimens obtained at St. David's.

Four of the cranidia, with lengths varying from 15 to 25 mm., have the characters of adult individuals, but do not exhibit the very pronounced enlargement of the glabella beyond the anterior margin that is shown in Salter's figures (*op. cit.* pl. iii, figs. 1 & 2). The fifth cranidium (Pl. IV, fig. 4) is 12 mm. long, and shows characters attributed to immature forms.

The glabella is strongly convex, widest at about two-fifths of its length from the front, and has the anterior of the four pairs of furrows just behind this point, not in advance of it, as shown by Salter. In the immature form, however, this furrow lies farther forward, and in agreement with the figures of the St. David's specimens.

The posterior furrows cross the axial line, but the others are interrupted towards the middle; all, except the anterior pair, are connected with the axial furrow. The occipital furrow is bent a little forwards in the middle; and the occipital ring is decidedly broader than the posterior glabellar lobes.

The fixed cheek is but slightly convex, and the eye-lobe is separated from it by a strongly marked parallel hollow. In the largest specimen (fig. 2 *a*) the length of the eye-lobe is a third of that of the cranidium; in the medium-sized specimens (fig. 3) the length of the eye-lobe is rather greater; and in the immature form (fig. 4) it is more nearly a half. The anterior border is narrow, nearly straight on either side, and somewhat obscured in front by the overhanging glabella; but in the smallest head-shield the fold stands clear of the glabella by a distance equal to about half its width.

The characters of the test are very well shown on specimen No. 2376, from which fig. 2 was drawn. The glabella is quite smooth on the frontal lobe, but granular on the central and posterior portions. On the cheeks (fig. 2 *d*) the granulations become coarser, but are not so much elongated as is indicated in Salter's figures (*op. cit.* figs. 1 & 2); on the occipital ring they are, however, elongated, and arranged more or less concentrically round a node or low tubercle in the middle of the ring (Pl. IV, fig. 2 *c*).

The two free cheeks which may be referred with little hesitation to the species (figs. 1 & 5) belong to larger individuals. The area is decidedly wide, particularly near the posterior margin, but in both specimens it is crushed to a mosaic, and its original form cannot be accurately determined; the marginal fold is fairly convex, and is continued to form a long and sharp spine, the length of which is about equal to that of the cheek itself. The upper surface of the fold shows a few raised lines, which creep over the margin on to the doublure, where they become more plentiful. In Salter's description the margin is said to be smooth. On specimen No. 2422 (Pl. IV, fig. 1) a few similar lines are to be seen on the under side to the area of the cheek, where they run in a direction sub-parallel of the curve of the eye.

Locality and horizon.—Neve's Castle (Shropshire), near the southern end of the Wrekin. Middle Cambrian.

Conclusions.

The rock-specimens, in which the two species of *Paradoxides* are found, contain a few other fossils, among which the following have been recognized:—

Agnostus sp., cf. *A. fallax* Linnarsson.
Agnostus sp., of the type of *A. cicer* Tullberg.
Ptychoparia (Liostracus) sp., compare the forms from Comley.
Agraulos sp., cf. *A. quadrangularis* (Whitfield).
Hyolithus sp.
Hyolithellus sp., cf. *H. fistula* Hall.
Acrotreta sp.

Until further specimens of the smaller trilobites are forthcoming, it is impossible to say definitely which horizon of the Middle Cambrian is represented.

Paradoxides hicksi, the two above-named species of *Agnostus*, and a similar form of *Liostracus* are found in the *Tessini* Zone of Scandinavia.

For previously-published references to the Neve's Castle locality see:—

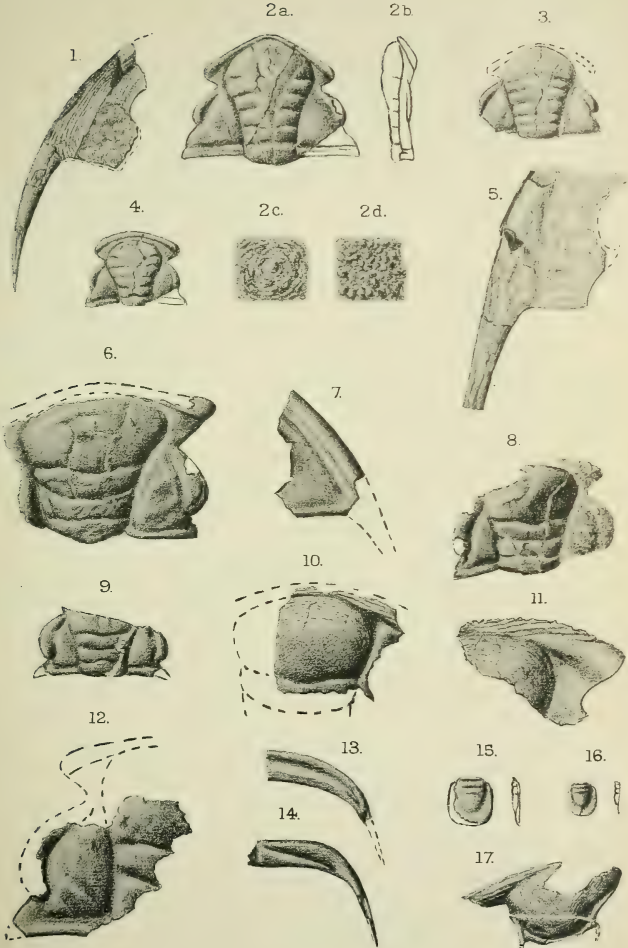
1877. C. Callaway, Q. J. G. S. vol. xxxiii, p. 662.
1894. C. Lapworth & W. W. Watts, Proc. Geol. Assoc. vol. xiii, p. 310.
1910. C. Lapworth & W. W. Watts, Geol. Assoc. Jubilee vol. pt. 4, p. 750.
1911. E. S. Cobbold, Q. J. G. S. vol. lxvii, p. 283.

EXPLANATION OF PLATE IV.

[All figures are of the natural size, except 2 *c* & 2 *d*. The letters and numbers in square brackets are those attached to the specimens.]

Paradoxides hicksi Salter. (See p. 47.)

Fig. 1. Free cheek [R.R. 2422].
2. Nearly complete cranidium, somewhat flattened [R.R. 2376]: *a*, seen from above; *b*, seen from the side; *c*, enlargement of the median part of the occipital ring; *d*, enlargement of part of a fixed cheek.
3. Incomplete cranidium, somewhat flattened [R.R. 2394].
4. Nearly complete cranidium of immature individual [R.R. 2380].
5. Free cheek of a comparatively large individual, much crushed [R.R. 2422].



E.S.C., Del.

Bemrose, Collo., Derby.

PARADOXIDES FROM NEVE'S CASTLE (SHROPSHIRE).

Paradoxides bohemicus Bœck, var. *salopiensis*, nov. (See p. 45.)

Fig. 6. Cranidium, somewhat flattened [R.R. 2385].
7. Free cheek, referred with reserve to this species and variety [R.R. 2435]
8. Cranidium, somewhat flattened and crushed [R.R. 2485].
9. Fragmentary cranidium, less flattened [2415].
10. Dome of glabella, showing rugosities [R.R. 2429].
11. Dome of glabella and part of margin, showing rugosities [R.R. 2388].
12. Part of cranidium of larger individual, showing the posterior branch of the facial suture [R.R. 2416].
13. Part of one of the anterior (?) pleuræ [R.R. 2423].
14. Complete pleura, from the posterior (?) part of the thorax [R.R. 2387].
Figs. 15 & 16. Pygidia, seen from above and from the side [R.R. 2382 & 2420].
Fig. 16. Hypostoma and doublure [R.R. 2427].

Discussion on the two foregoing Papers.

Mr. W. G. Fearnsides congratulated the Author on his palæontological discoveries, and on the close parallelism which he had been able to prove between the Middle Cambrian rocks of Shropshire and the *Paradoxides-tessini* Zone of Sweden.

As bearing upon the mode of accumulation of the fossiliferous breccias described, he drew attention to the following points:—

(1) The fossiliferous matrix of the breccia contains glauconite.
(2) The enclosed fragments of the Lower Cambrian rocks are quite unweathered; they too are glauconite-bearing, while the fossils which they contain are preserved unaltered and consist largely of calcite.
(3) All the included fragments are markedly angular, and many of them have bounding-surfaces which meet at acute angles.

On this evidence the speaker would conclude that the erosion which broke up the Lower Cambrian sandstone into fragments took place *in situ*, and was not a subaërial but a submarine process. He suggested that the Lower and Middle Cambrian rocks of Shropshire, like the contemporaneous rocks of Northern Œland, are the record of a condition when sedimentation and submarine erosion were nicely balanced; when only the larger fragments, and the interstitial sand sheltered between them, remained unmoved by the currents, and were preserved as sedimentary rock. The occurrence of phosphatic nodules in beds interstratified with glauconitic sandstones also pointed to the same conclusion.

Mr. G. W. Lamplugh remarked that marine sedimentation was often a discontinuous process, and that gaps in a stratigraphical sequence, even when accompanied by erosion, did not necessarily imply elevation above sea level. Among the Mesozoic rocks it was not unusual to find glauconitic and phosphatic deposits of little thickness, which evidently represented long periods of arrested sedimentation, and sometimes of submarine erosion. It was also known that the floors of our present seas were being scoured and eroded in many places.

Prof. W. W. Watts pointed out that phenomena of brecciation like those described by the Author were being recognized as of frequent occurrence, especially in limestones. They were especially well known in cornstones and in limestones of tufaceous character, but they were also found in such well-bedded marine limestones as those of the Carboniferous System. Hitherto, no general explanation of the phenomena had been given.

Mr. E. Greenly, while admitting the possibility of contemporaneous erosion, thought that an unconformity was to be expected at the horizon mentioned. Despite the thickness of the Cambrian deposits of Carnarvonshire, the zone of *Olenellus* had not yet been detected. Cleavage, it was true, was strong; but the evidence now brought forward by the Author tended to confirm the suspicion that the *Olenellus* Zone might have been overlapped, or even removed, by erosion along the slope of the old land, at a very early period.

The Author, in reply, said that there were phosphatic beds among the Cambrian rocks of Comley which might mark pauses in the sedimentation, but these were distinct from the breccias or conglomerates. The breccias and conglomerates he regarded as representing detritus from cliffs or islets, rather than as the result of what was formerly called 'contemporaneous erosion.' The older fossils found in them were furnished by the angular blocks, and belonged to the *Protolenus-Callavia* Fauna, which, on the analogy of American sections, occurred well down in the Lower Cambrian; Dr. Walcott had shown that the telson-bearing *Olenelli*, which had not as yet been found in Shropshire, marked a higher horizon than that of the *Protolenus* Fauna.

The palæontological break between the Lower and the Middle Cambrian of Comley, as described by the Author in a previous communication to the Society, was very great, and was matched by the physical unconformity which the excavations had proved to exist in the district. This unconformity appeared to be just what was required for the elucidation of the hiatus mentioned by Mr. Greenly.

In conclusion, the Author thanked the Fellows for their kindly reception of his papers.

5. *On the* Genus *Aulophyllum*. By Stanley Smith, B.A., M.Sc., F.G.S., Clare College, Cambridge. (Read November 20th, 1912.)

[Plates V–IX.]

Contents.

I. Introduction.

Aulophyllum occurs in the higher horizons (the *Dibunophyllum* Zone) of the Lower Carboniferous of Great Britain, and is particularly abundant in Scotland and the North of England. Mr. J. A. Douglas has recorded '*Cyclophyllum* sp.' from the Carboniferous Limestone (D) of County Clare (Ireland),[1] and Dr. A. Vaughan '*Cyclophylla*' from the equivalent horizon at Visé (Belgium)[2]; while Kunth reported its occurrence at Hausdorf, near Glatz, on the south-western border of Silesia.[3] Mr. R. G. Carruthers has described a specimen from Novaya Zemlya,[4] which proved its existence at as high a latitude as 70° 49′ N. Dr. G. H. Girty, on the other hand, believes that the genus has not been recorded from the United States.[5]

The corals studied were partly collected by myself, but for a large portion of the material I am indebted to the generosity of Mr. John Bishop, Mr. R. G. Carruthers, Mr. John Dunn, Prof. E. J. Garwood, Dr. W. T. Gordon, Mr. Leonard Gill, Mr. Thomas Herdman, Dr. Wheelton Hind, Mr. W. B. R. King, Dr. F. L. Kitchin, Mr. A. F. Sandys, Dr. T. F. Sibly, Mr. C. T. Trechmann, Dr. Arthur Vaughan, Mr. F. H. Walker, Mr. Geoffrey Weyman, and Dr. Albert Wilmore.

The preparation of material, its examination, and the literary

[1] 'The Carboniferous Limestone of County Clare (Ireland)' Q. J. G. S. vol. lxv (1909) p. 555.
[2] 'Faunal Succession in the Lower Carboniferous (Avonian) of the British Isles' Rep. Brit. Assoc. 1910 (Sheffield) table facing p. 108.
[3] See Bibliography, § II [11].
[4] *Ibid.* [14].
[5] Private communication.

research have been carried out at the Sedgwick Museum, Cambridge; and I take this opportunity of expressing my thanks to Prof. T. McKenny Hughes, F.R.S., for these privileges and for the kindly interest that he has shown in my work.

My thanks are also cordially tendered to all those who have aided me with suggestions and criticism, especially to Mr. R. G. Carruthers, Mr. W. D. Lang, Mr. Henry Woods, and Dr. Arthur Vaughan.

Lastly, I thank Mr. Frederick Phillips for his assistance in the preparation of sections.

II. Literature.

(1) Synonymy.

Only the more important works bearing upon the coral are here enumerated.

[1] 1793. *Fungites* .... Ure, D. 'The History of Rutherglen & East Kilbride' pp. 327–28 & pl. xx, fig. 6.

[2] 1828. *Turbinolia fungites* .... Fleming, J. 'A History of British Animals' p. 510.

[3] 1830. *Turbinolia fungites* .... Woodward, S. 'A Synoptical Table of British Organic Remains' p. 7.

[4] 1834. *Turbinolia fungites* .... De Blainville, H. M. D. de. 'Manuel d'Actinologie ou de Zoophytologie' p. 342.

[5] 1846. *Cyathophyllum fungites* ... Geinitz, H. B. 'Grundriss der Versteinerungskunde' p. 571.

[6] 1849. *Clisiophyllum prolapsum* ... M'Coy, F. 'On some New Genera & Species of Palæozoic Corals & Foraminifera' Ann. Mag. Nat. Hist. ser. 2, vol. iii, p. 3.

[7] 1850–54. *Aulophyllum* .... Milne Edwards, A., & Haime, J. 'A Monograph of the British Fossil Corals' pp. lxx & 188–89, pl. xxxvii, fig. 3, pl. xxxviii, fig. 1 (Pal. Soc.).

[8] 1851. *Aulophyllum* .... *Idd.* 'Monographie des Polypiers Fossiles des Terrains Paléozoïques' pp. 413–14.

[9] 1854. *Clisiophyllum prolapsum* ... M'Coy, F. 'A Systematic Description of the British Palæozoic Fossils in the Geological Museum of the University of Cambridge' pp. 95–96 & pl. iii *c*, figs. 5–5 *a*.

[10] 1867. *Cyclophyllum.* / *Aulophyllum.* } .... Duncan, P. M., & Thomson, J. 'On *Cyclophyllum*, a New Genus of the Cyathophyllidæ, with Remarks on the Genus *Aulophyllum*' Q. J. G. S. vol. xxiii, pp. 327–30 & pl. xiii.

[11] 1869. *Aulophyllum* .... Kunth, A. 'Beiträge zur Kenntniss fossiler Korallen' Zeitschr. Deutsch. Geol. Gesellsch. vol. xxi, pp. 201–205 & pl. iii, figs. 2 *a*–2 *b*.

[12] 1882. *Cyclophyllum.* / *Aulophyllum.* } .... Thomson, J. 'On a New Family of Rugose Corals, including the Genera *Cyclophyllum*, *Aulophyllum*, & on the Genus *Clisiophyllum*' Proc. Glasgow Phil. Soc. vol. xiii, pp. 471–516 & pls. i–iv.

[13] 1906. *Cyclophyllum* .... VAUGHAN, A. 'The Carboniferous Limestone Series (Avonian) of the Avon Gorge' Proc. Bristol Nat. Soc. ser. 4, vol. i, p. 146.

[14] 1909. *Aulophyllum* .... CARRUTHERS, R. G. 'A Carboniferous Fauna from Novaya Zemlya collected by Dr. W. S. Bruce, by G. W. Lee; with Notes on the Corals by R. G. Carruthers' Trans. Roy. Soc. Edin. vol. xlvii, p. 149.

Non

1808. *Fungites* .... PARKINSON, J. 'Organic Remains of a Former World' vol. ii, p. 120.

1836. *Turbinolia fungites* .... PHILLIPS, J. 'Illustrations of the Geology of Yorkshire' pt. 2, p. 203 & pl. ii, fig. 23.

1842–44. *Cyathophyllum fungites* . KONINCK, L. G. DE. 'Description des Animaux Fossiles qui se trouvent dans le Terrain Carbonifère de Belgique' p. 24 & pl. D, fig. 2.

1843. *Cyathophyllum fungites*...... PORTLOCK, J. E. 'Report on the Geology of Londonderry, & of parts of Tyrone & Fermanagh' p. 328.

(2) Summary of the Work of Previous Authors.

The genotype of *Aulophyllum* was figured and described by David Ure in 1793 as *Fungites* [1].[1] The name *Fungites* was originally given by Martini to a *Halysites*-like form, *Fungites catenulatus*, in 1765.[2] In 1828 Fleming assigned Ure's form to the genus *Turbinolia* [2] of Lamarck[3] (an aporose form), and used '*Fungites*' in the specific sense; hence to him must be credited the authorship of the species *fungites*. Geinitz, in 1846, transferred the species to the genus *Cyathophyllum* [5] of Goldfuss.[4] M'Coy, in 1849, described some specimens of the coral in the Woodwardian Museum, Cambridge, and referred them to Dana's[5] genus *Clisiophyllum*, naming them *Clisiophyllum prolapsum* [6]. Milne Edwards & Haime took M'Coy's species as the genotype of their new genus *Aulophyllum* [7] in 1850, and described it as follows, [7] p. lxx:—

'Corallum simple. Septa well developed. A double mural investment; the interior wall dividing the visceral chamber into two portions—one central and columnar, the other exterior and annular. No columella. Tabulæ but little developed.'

M'Coy objected to the establishment of the new genus in his next publication (1854) [9] on the grounds that its characters were

[1] Numerals in square brackets refer to the papers enumerated in the foregoing bibliography.
[2] F. H. W. Martini, Berl. Mag. vol. i, p. 268 & pl. i, fig. 4.
[3] J. B. P. A. de M. Lamarck, 'Histoire Naturelle des Animaux sans Vertèbres' vol. ii (1816) p. 230.
[4] A. Goldfuss, 'Petrefacta Germaniæ' (1826) p. 54.
[5] J. D. Dana, 'Zoophytes: U.S. Exploring Expedition' vol. vii (1846) pp. 361–62 & pl. xxvi, figs. 6–7.

insufficient to justify this generic separation. He stated, [9] pp. 95 & 96, that

'This species forms the type of the genus *Aulophyllum* of MM. Milne-Edwards and Haime, from the definite tubular boundary to the inner area or axis; this, however, is merely a question of degree, serving to distinguish a well-marked species, but scarcely applicable as grounds of generic division; for this inner area or axis is more or less defined in all [*Clisiophylla*], and different parts or ages of the same specimen show variation in this respect.'

In his figure, however, M'Coy represents the 'boundary to the inner area' as being much thicker and more solid than it really is; while he shows the tissue within this wall as thin and crowded, dome-like tabulæ, and does not emphasize its true composite nature.

In criticizing the statements and conclusions of the earlier authors, it must not be forgotten that their researches were made without the aid of thin sections.

M'Coy's observation that the wall is a character common to all members of his accepted genus *Clisiophyllum* is correct, in so far as the term merely defines the limit of the central column. His objection to the generic separation of the species *prolapsum*, merely upon the more pronounced nature of the boundary of the inner area, is scientifically sound and reasonable. Were the division of *Aulophyllum* from *Clisiophyllum* solely dependent upon that feature, his views regarding the generic identity of the two would be unassailable.

In addition to the accentuated boundary, the central portion of *Clisiophyllum prolapsum* exhibits other and more important differences which distinguish it from the other species of the genus described by M'Coy. It has no columella or mesial plate, and the central tissue consists of small, irregular tabulæ, concave towards the calyx, surrounded by plates bent sharply towards the proximal end of the corallum; while in *Clisiophyllum* proper, simpler tabulæ slope at a more gentle angle from the trabeculate columella. The vertical lamellæ of the central column are far more numerous in *Aulophyllum* than in *Clisiophyllum* and its allies. Although the distinctive features of *Aulophyllum* separate it from the latter, yet the possession of a distinct central column containing lamellæ, groups these into a well-marked sub-group of the Cyathophyllidæ—the Clisiophyllidæ.

Milne Edwards & Haime replied to M'Coy's criticism in a later part of their monograph, maintaining that their reasons for generic separation were valid. They described two species, *Aulophyllum fungites* and *A. bowerbanki*,[1] the specific differences between these being that the former had more numerous septa, and an inner wall wider in proportion to the diameter of the corallum than the latter.

Duncan & Thomson, in 1867 [10], expressed the opinion that *A. fungites* and *A. bowerbanki* could not remain in the genus *Aulophyllum* as defined by the French authors, maintaining that

[1] *A. bowerbanki* is described in Milne Edwards's & Haime's monograph as having been found in Ireland. The type-specimen preserved in the British Museum is labelled 'Oswestry.'

these forms did possess a columella. On this ground they created a new genus, *Cyclophyllum*, and restricted *Aulophyllum* to forms in which the middle portion of the central column is occupied by tabulæ only, and not invaded by the septal lamellæ. Their description of *Cyclophyllum* was as follows (*op. cit.* p. 328):—

'The corallum is simple, tall, cornute, or more or less cylindrical. The wall is very thin, and is formed of epithecæ. The calice is deep, and its margin sharp; there is a central projection at the bottom of the fossa, separated from the ends of the larger septa by a deep groove. This central mass consists of an endothecal covering, with numerous septa attached to it internally, and coalescing to form some large septa, which ramify over the central depression which represents the top of the columella.

'The columella is essential, and is made up of laminæ which arise from the base of the corallum, and from the dissepiments which unite them. The endotheca is largely developed, and the septa are very numerous. There is a fossula with three small septa in it, and a process of the endotheca of the central mass projects into it.'

The separation appears, at first sight, a very reasonable and desirable one. Closer investigation, however, discloses serious objections.

The authors state that a columella is essential; but, after a careful study of Thomson's figures published in his second paper and also of many actual specimens, I am convinced that no columella occurs, not even a pseudo-columella. It is true that the lamellæ within the 'central mass' (defined by Thomson [12] as 'septa') do coalesce 'to form some large septa, which ramify over the central depression,' the result being a network of tissue weakening towards the centre. In most specimens some of the lamellæ reach the centre of this inner area; but in a few cases they all fail to do so, and the Aulophylloid character is produced. This may happen at different parts of the same individual. I am, therefore, compelled to reject the genus *Cyclophyllum*, and to refer all forms of Thomson's 'Diplocyathophyllidæ' to *Aulophyllum*. Kunth included a description of the genus as *Aulophyllum fungites* in his paper on fossil corals (1869) [11], and identified with it Ludwig's species *Cyathodactylia undosa* and *C. stellata* [1]; but neither the definition nor the figures of these are convincing. The latter, in fact, bear little resemblance to *Aulophyllum*.

In 1882 Thomson published a second paper [12] dealing with *Cyclophyllum* and *Aulophyllum* at some length. He embodied in it the conclusions drawn from the examination of over eight hundred sections of *Cyclophyllum* and twenty sections of *Aulophyllum* from the Carboniferous Limestone of Scotland. He acknowledged the close relationship existing between his two genera by placing them in a new family, which he called Diplocyathophyllidæ. He, further, cut the original specimen of Ure's *Fungites* preserved in the collection of the Royal Society of Edinburgh, giving illustrations of the sections (*op. cit.* pl. ii, figs. 1, 1 *a*, & 1 *b*), and described it as *Cyclophyllum fungites*, maintaining that it had 'no generic relationship

[1] R. Ludwig, 'Corallen aus Paläolithischen Formationen' Palæontographica, vol. xiv (1865–66) pp. 160–61 & pl. xxxvi, figs. 1–2.

to the genus *Aulophyllum'* (pp. 480–81), his reasons being the presence of what he considered the columella. The following species were described by him:—

CYCLOPHYLLUM:

C. fungites, C. urcanum, C. bowerbanki,[1] *C. biacuminatum, C. pachyendothecum, C. obovatum, C. scoulerianum, C. duncanianum, C. ellipticum, C. orbiculum, C. carpenterianum, C. bennieanum, C. m'kendrickianum, C. curvilineare,* C. concentricum, C. cylindricum, C. frondicum,* C. tortuosum, C. paradoxacum,* C. intermedium, C. radianum,* C. moseleyanum, C. vesicularum.*

AULOPHYLLUM:

A. patrickianum, A. fungites, A. edwardsianum, A. haimeianum, A. wünschianum, A. impingeum, A. expansum.*

These different species are carefully figured, and, with the exception of those indicated by an asterisk (which appear to be Clisiophylloid forms),[2] agree very closely in plan. The differences expressed in the figures: that is, the size, shape, and structure of the central axis, the width of the space between the axis and the ends of the septa, and the character of the outer zone of the fine dissepiments, may be assigned to individual variability and to the particular stage of development of the corallum at which the section was cut. Plate-space will not allow full demonstration of these assertions, although the opinions here expressed result from the examination of many sections. Nevertheless, figs. 5 *a*–5 *c* & 7 *a*–7 *b* in Pl. V, and 1 *a*–1 *c* in Pl. IX, illustrate the marked difference existing between sections from the same coral. Furthermore, the longitudinal sections 4 *b* in Pl. VI & 3 *b* in Pl. VII show by the variable character of the central tissue how sections cut at different horizons must necessarily vary.

The results of my investigation, therefore, lead me to regard all Thomson's species (with the exceptions before noted) as possible varieties of one species. My conclusions respecting the identity of *Aulophyllum* and *Cyclophyllum* have been anticipated by opinions expressed by both Dr. A. Vaughan [13] and Mr. R. G. Carruthers [14].

III. SOURCES OF MATERIAL STUDIED.

The following table shows the localities from which the corals examined were obtained, and the palæontological horizon of the beds in which they occurred. Accounts of the Lower Carboniferous palæontology will be found in the papers mentioned in the list of authorities below; reference-numbers to these are given in the third column:—

[1] *Cyclophyllum bowerbanki* Thomson does not answer the description of *Aulophyllum bowerbanki* Ed. & H.

[2] In the absence of the original type-specimens, which were unfortunately destroyed by fire, any critical survey of Thomson's types is inadvisable.

Locality.	*Horizon.*	
Scotland.		
Linlithgow (Bathgate).	Upper *Dibunophyllum* Zone.	
Fifeshire.	Do. do. do.	14
North of England.		
Northumberland.	D_1, D_2, & D_3, chiefly D_3.	2 & 9
North-East Cumberland (country round Alston).	D_2–D_3.	4
Durham (Weardale).	D_3.	5
North Yorkshire (Wensleydale).	D_2–D_3.	1
West Yorkshire (Craven District).	D_2–D_3.	15
South Cumberland and North Lancashire (country round Morecambe Bay).	D_2–D_3.	3
Derbyshire.	D_2, D_2–D_3.	8
North Wales and Borders.		
Oswestry.	Upper *Dibunophyllum* Zone.	6
Anglesey.	Do. do. do.	13
South Wales.		
Tenby.	D_1.	10
South-West of England.		
Bristol.	D_1.	12 & 13
Mendips.	D_2.	7

List of Authorities.

(1) Garwood, E. J.—'Notes on the Faunal Succession in the Carboniferous Limestone of Westmoreland & Neighbouring Portions of Lancashire & Yorkshire' Geol. Mag. dec. 5, vol. v (1907) p. 70.

(2) Garwood, E. J.—'The Geology of Northumberland & Durham' Geology in the Field. Geol. Assoc. Jubilee vol. pt. 4 (1910) pp. 671–83.

(3) Garwood, E. J.—'The Lower Carboniferous Succession in the North-West of England' Q. J. G. S. vol. lxviii (1912) p. 449.

(4) Herdman, T.—A forthcoming paper on the Faunal Succession in the Carboniferous Limestone Series around Alston.

(5) Hind, Wheelton.—'Life-Zones in the British Carboniferous Rocks' Rep. Brit. Assoc. 1906 (York) p. 308.

(6) Lomas, J.—'The Geology of the Berwyn Hills' Proc. Geol. Assoc. vol. xx (1908) p. 485.

(7) Sibly, T. F.—'On the Carboniferous Limestone (Avonian) of the Mendip Area (Somerset), with especial reference to the Palæontological Sequence' Q. J. G. S. vol. lxii (1906) p. 324.

(8) Sibly, T. F.—'The Faunal Succession in the Carboniferous Limestone (Upper Avonian) of the Midland Area (North Derbyshire & North Staffordshire)' Q. J. G. S. vol. lxiv (1908) p. 34.

(9) Smith, Stanley.—'The Faunal Succession of the Upper Bernician' Trans. Nat. Hist. Soc. Northumberland, &c. n. s. vol. iii, pt. 2 (1910) p. 591.

(10) Strahan, A., Cantrill, T. C., Dixon, E. E. L., & Thomas, H. H.—'The Geology of the South Wales Coalfield—Part X: The Country around Carmarthen [Sheet 229]' Mem. Geol. Surv. 1909.

(11) Vaughan, A.—'The Palæontological Sequence in the Carboniferous Limestone of the Bristol Area' Q. J. G. S. vol. lxi (1905) p. 181.

(12) Vaughan, A.—'The Carboniferous Limestone Series (Avonian) of the Avon Gorge' Proc. Bristol Nat. Soc. ser. 4, vol. i (1906) p. 74.

(13) Vaughan, A.—'Faunal Succession in the Carboniferous Limestone (Avonian) of the British Isles' Rep. Brit. Assoc. 1908 (Dublin) p. 267.

(14) Vaughan, A.—'Faunal Succession in the Lower Carboniferous Limestone (Avonian) of the British Isles' Rep. Brit. Assoc. 1909 (Winnipeg) table iii, facing p. 190.

(15) Wilmore, A.—'On the Carboniferous Limestone South of the Craven Fault (Grassington-Hellifield District)' Q. J. G. S. vol. lxvi (1910) p. 539.

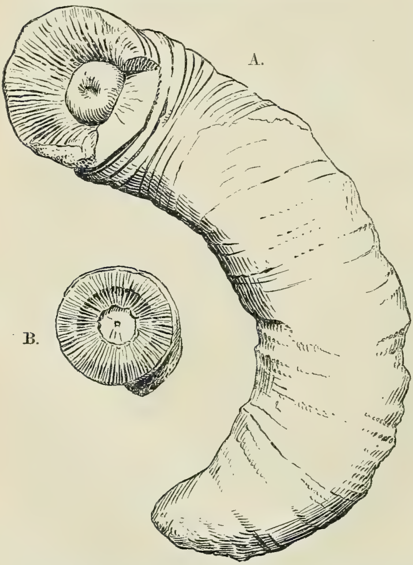
Note on Peterhill Quarry, Bathgate (Linlithgowshire).

Peterhill Quarry, now converted into a reservoir, has provided a great part of my material; although this limited collecting-ground only consists of an exposure extending for a few yards along the side of the water, the corals lie thickly crowded together in a calcareous bed 2 feet thick, and are also plentiful throughout the few feet of shale that separate it from the thicker encrinital limestone below. Dibunophyllids and large Zaphrentids are plentiful, but in numbers *Aulophyllum* far exceeds the other simple forms. The corals are remarkable for their fine state of preservation, and for the very wide range of variations represented in *Aulophyllum*. Further interest and importance are attached to the exposure, on account of Thomson having collected here a large number of the forms figured in his paper on *Aulophyllum* and *Cyclophyllum*.

IV. General Description of the Genus.

(1) External characters.—*Aulophyllum* may attain a considerable size and length, and in certain localities, and even in particular quarries, large specimens are especially abundant. The largest that I have obtained came from Triflach-Wood Quarry near Llanymynech; it was 40 cms. long, and had a maximum diameter of 4 centimetres.

Fig. 1.—Aulophyllum: $\frac{2}{3}$ *nat. size.*



[The specimens are preserved in the Museum of Practica Geology, Jermyn Street, London. A is No. 25434 from Chapel, near Kirkcaldy (Fifeshire); B is No. 26255 from Peterhill Quarry, Bathgate.]

The corallum, in the young state, is cornute, but later it becomes cylindrical. The shape is, however, often modified by irregularities of growth and rejuvenescence. Increase in diameter generally progresses with comparative rapidity in proportion to growth in length: hence

the very graceful curvature so characteristic of *Zaphrentis* is comparatively rare. On the other hand, I have not seen a single example of the turbinate form, so common in *Dibunophyllum*, although obtusely turbinate members of that genus are found associated with *Aulophyllum* at Peterhill. The calyx is moderately deep, and possesses a stout wall. From its depressed base there generally rises a prominent protuberance (the central column) (fig. 1 A); but in some cases this feature is so inconspicuous (fig. 1 B), that a longitudinal section is required to demonstrate the presence of this feature. The middle of the central column is usually occupied by a small pit. The fossula is not easily seen, but is nearly always situated on the convex side of the corallum. The appearance of the calyx in many specimens is greatly modified by corrosion prior to entombment, as well as by subsequent weathering in the exposed rock. Slight constrictions are frequent, and give rise to ridges encircling the corallum, which converge and even intersect on the concave side in its trochoid stage, but are parallel in the cylindrical. The more marked constrictions, due to rejuvenescence, are of less common occurrence.

(2) Internal characters.—Since structural details will be fully treated in subsequent sections of this paper, it is here necessary to outline only the general plan of coral anatomy. The corallum, if its very young stages be disregarded, may be considered as built up of three concentric cones:—

(i) An innermost cone (the central column). This is formed of irregular vesicles, the innermost members of which are small and concave towards the calyx, while encircling them are plates bent towards the proximal end of the corallum into an almost vertical position (as, for example, fig. 4 *b* in Pl. VI). These outer vesicles form the 'wall' of the central column. The inner vesicles will be referred to as 'central vesicles,' and the outer vesicles, for the sake of distinction, as 'pericentral vesicles.' These vesicles are cut by vertical plates (the septal lamellæ) which radiate inwards from the boundary of the column. The boundary of the column is almost regular; but there are slight indications of alternating restricted and bulging portions.

(ii) A middle cone, in which large irregular vesicles (the tabular vesicles)[1] lie inclined from the central column, and are convex towards the exterior of the corallum. A single flattened vesicle may extend across the zone, but usually two, three, or even more are required to bridge the space.

[1] 'Inner dissepiments' of most authors.

(iii) An outer cone of smaller and more regular vesicles (the dissepiments proper). These dissepiments are more arched than the tabular vesicles, and their convexity is towards the middle of the corallum.

The septa are of two orders, major and minor. The major septa extend nearly to the central column, leaving, however, an annular space around it, traversed sporadically only by lamellæ joining the ends of the septa with the inner zone. The minor septa usually cross the dissepimental zone, but do not extend far into the area occupied by the tabular vesicles.

The cardinal fossula is conspicuous; it is occupied by a short cardinal septum, and in the young and adolescent stages by two developing septa. Alar fossulæ are seen only in the immature stages, and are situated between 80° and 90° from the cardinal fossula, shown well in Pl. V, fig. 7 *a*.

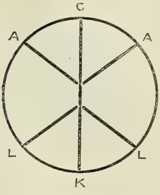
V. Ontogenesis.

First the origin and growth of the component parts of the corallum will be described in detail, then will follow a more cursory survey of the development of the corallum considered as a whole.

Origin and Growth of the Component Parts of the Corallum.

(*a*) Major septa.—Mr. R. G. Carruthers[1] has shown that the primary septal plan of the Rugosa is hexamerous, as in the case of the Aporosa; but, unlike the newer Zoantharians, which form their six primary septa simultaneously, the nepionic Rugosa first laid a single septum extending across the corallum (the axial septum), which subsequently broke in two to form the cardinal and counter-septa. From the axial septum sprang two pairs of septa, the alar and counter-lateral.

Fig. 2.—(*After Carruthers.*)



C–K = Axial septum.
C = cardinal septum.
A = alar septa.
K = counter-septum.
L = counter-lateral septa.

The first four secondary septa then appeared (1 *a*, 1 *a*′, 1 *c*, & 1 *c*′) in the position indicated in the diagram (fig. 3).

Four more (2 *a*, 2 *a*′, 2 *c*, & 2 *c*′) were then added, at the side of these, as shown in the diagram (fig. 4, p. 61).

In this manner successive fours followed

[1] 'The Primary Septal Plan of the Rugosa' Ann. Mag. Nat. Hist. ser. 7, vol. xviii (1906) pp. 356–63.

as the coral developed. Thus new septa appeared at both sides of the cardinal septum and immediately behind the alar septa, and three breaks or fossulæ were formed. The pinnate plan outlined by Kunth was thus designed.[1]

As this insertion of secondary septa took place, the alar septa moved round until they occupied a position approximately 80 from the cardinal septum, and the counter-lateral approached the counter-septum until the space between it and the former corresponded to other interseptal spaces. The present investigation has shown, however, that the first four secondary septa were not formed simultaneously, but those which originated at the alar fossulæ appeared first. These were followed by the two in the cardinal fossula. This order of the insertion of secondary septa was continued throughout the growth of the coral, and is illustrated in the diagram (fig. 5); $2\,a$ and $2\,a'$ appeared before $2\,c$ and $2\,c'$ (a and a' being those originating at alar fossulæ and c and c' those at the cardinal fossula), $3\,a$ and $3\,a'$ before $3\,c$ and $3\,c'$ . . . and ${}^{n}a$ and ${}^{n}a'$ before ${}^{n}c$ and ${}^{n}c'$; in some cases, however, more than one extra pair was added at the alar fossulæ. The result is that, except where irregularities occur, there are at least two more septa in the counter-septal quadrants than in the cardinal quadrants. In other words, there are two or more septa of alar-fossulæ origin more than of cardinal-fossula source.

Fig. 3.—*(After Carruthers.)*

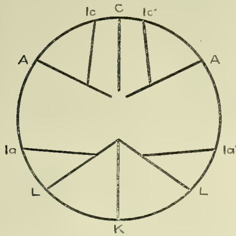


Fig. 4.—*(After Carruthers.)*

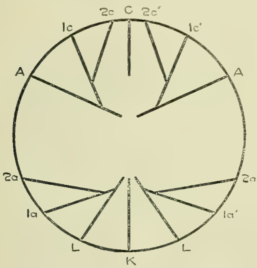
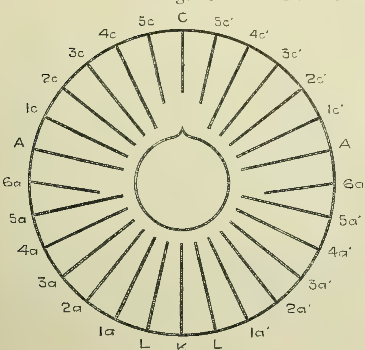


Fig. 5.



1 'Beiträge zur Kenntniss fossiler Korallen' Zeitschr. Deutsch. Geol. Gesellsch. vol. xxi (1869) p. 647.

The insertion of septa ceased when the corallum reached the cylindrical stage, and the last-formed septa having attained the same size as the others, the pinnate aspect was superseded by a bilateral, or even radial symmetry. *Aulophyllum* with other forms assumed a bilateral symmetry, in virtue of the shortened cardinal septum, which kept open the cardinal fossula. In those forms in which the cardinal septum was not conspicuously shortened the radial symmetry replaced the pinnate.

In Pl. V, fig. 1, the septa are seen to unite and coalesce in the centre of the corallum, but at a very early stage they became free; in Pl. V, fig. 2, this process is just commencing.

(*b*) Minor septa.—The first minor septa to appear in the coral were inserted between the already existing major septa, at a point situated a short distance from the proximal end of the corallum. The subsequent members were introduced at the fossulæ or after the last-formed major septa had developed: that is, between 5 *c* and 4 *c*, and between 6 *a* and 5 *a*.

(*c*) Septal lamellæ.—In a section through the very young portion of the coral, the major septa penetrate the wall of the central column, and are prolonged within it as thin flexuous lamellæ (Pl. V, fig. 3). The septa retreated, however, as development progressed, and (Pl. V, fig. 4) eventually left a clear annular space between their ends and the central column (Pl. V, fig. 5 *a*). The thin lamellæ thus either became free, or remained connected to the ends of the septa as before (Pl. V, fig. 4); but later most, if not all, became separate (Pl. V, fig. 5 *a*). Simultaneously with this development, fresh lamellæ grew out from the 'wall' of the central column between the existing lamellæ of direct septal origin: hence the number of septal lamellæ greatly exceeds that of the septa.

In the earliest stages, the septal lamellæ merely fringe the inner wall of the central column (Pl. V, figs. 3 & 4); but certain of their number soon advanced into the vesicular tissue, and the rest converged with these longer ones (Pl. V, figs. 5 *a*–5 *c*). The character of the septal lamellæ, as shown elsewhere (p. 67), is very variable, and their development is irregular; but generally a radial arrangement, in which the lamellæ are fairly straight and not in a crowded condition (Pl. V, figs. 5 *b* & 7 *a*), precedes a more irregular plan of compacted lamellæ (Pl. V, figs. 5 *c* & 7 *b*).

(*d*) Columnar and tabular vesicles.—One class of vesicles only—simple vesicles of a tabular character were formed near the proximal end of the corallum. These were followed by others, arched in the centre and bent backward towards the margin. The succeeding vesicles broke up into arched tabulæ and tabular

vesicles. These changes are shown diagrammatically below (fig. 6). They approximately synchronized with the separation of the septa at their inner ends. The arched tabulæ broke up further to form the 'walls' of the central column (the pericentral vesicles), and within these was laid the irregular tabular tissue (the central vesicles). Both the central and the pericentral vesicles became more numerous, and produced a denser structure (Pl. VI, fig. 4 *b* & Pl. VII, fig. 3 *b*).

Fig. 6.

(*e*) The dissepiments.—The development of the dissepiments followed upon the introduction of the minor septa. A single ring of dissepiments first appeared (Pl. V, fig. 5 *a*), but the number increased as the coral grew. The outward expansion of the zone was interrupted at short irregular intervals by a wider ring of dissepiments being followed by a narrower one. Thus sharp ledges check a short period of gradual expansion, and the result is the wrinkled aspect to which the Rugosa owe their name (fig. 1 *a*, p. 58).

The dissepiments are not derived from tabulæ, as are the tabular vesicles. They approach more closely the nature of cœnenchymatous tissue. In conjunction with the minor septa, their function may have been the expansion and strengthening of the calicular wall. A layer of dissepiments was deposited against the epitheca inside the rim of the calyx, at the same time as the floor of the calyx was raised by a fresh platform of inner tissue. Hence, at any one level, the outer dissepiments are of earlier growth than the tabular vesicles which abut against them.

Rate of Growth, and the Size attained.

The diametric measurements attained by a corallum differ greatly in different individuals, as also does the rate of development. Some individuals show signs of approaching maturity at the same distance from the proximal end and with the same diameter, at which others have only reached an early stage of development. Consequently, these forms remain dwarfed in size, so far as the diametric measurements are concerned (see Pl. V, figs. 8 & 9).

The comparison of individuals with reference to their height can serve no useful purpose, since it cannot be known to what length a certain coral might have attained had not the death of the polyp terminated its growth.

Brief Account of the Development of the Corallum considered as a whole.

(*a*) Stage A (nepionic stage).—This stage represents the period during which the six primary septa were formed. The character of the transverse section at the conclusion of this stage is shown in Pl. V, fig. 1. Close examination of this figure reveals the presence of two very young secondary septa, growing out of each of the counterlateral septa, so that it actually represents the beginning of Stage B.

(*b*) Stage B (Zaphrentoid stage).—The characters displayed at this stage are essentially those of *Zaphrentis*, and doubtless will prove eventually to be common to all Rugose forms. The septa meet and coalesce at the centre of the corallum, and are arranged in a pinnate symmetry; the cardinal fossula is very large. The vesicular tissue is of simple tabulate character. The whole plan is uni-areal. The tissue is usually stout in proportion to the size of the section, but even at this stage the greater development of stereoplasmic thickening in the septa which originate at the cardinal fossula may be observed. Pl. V, fig. 2 illustrates the general aspect of the transverse section at this stage, although the separation of the septa at the centre denotes the beginning of Stage C.

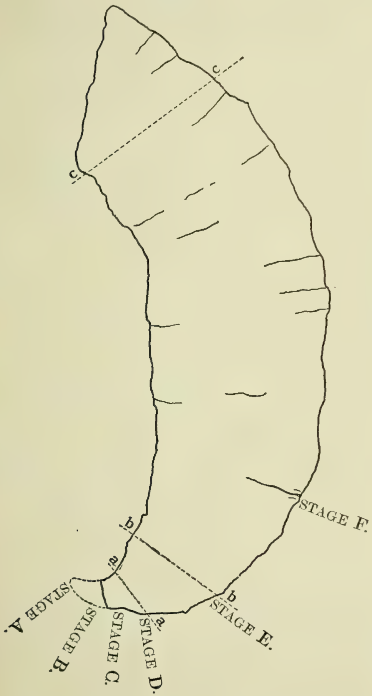
(*c*) Stage C.—At this stage the separation of the conjoined ends of the septa takes place, and the central column is developed. The pinnate symmetry and large fossula are pronounced features. The central column in the earlier phase of this stage is invaded by the septa, the reduced ends of which form a fringe of lamellæ. The columnar vesicles are represented at first by simple arched tabulæ, or the earliest derivations from the same, so that the middle of the column appears in the horizontal section almost void of tissue. The outer zone of fine dissepiments is absent, and the minor septa are absent or rudimentary. The plan is bi-areal. Pl. V, fig. 3 is the section typical of this stage; fig. 4 represents the aspect towards the end of the stage, the septa having withdrawn from the central column.

(*d*) Stage D.—All the characters of *Aulophyllum* are present at this stage of its development, but some as yet are rudimentary. The central column is free from the invasion of septa, and the short septal lamellæ at its periphery far exceed the septa in number; the principal lamellæ are few, and the transverse section presents a loose cellular appearance.

Differentiation between the central vesicles and the pericentral vesicles is complete, although the latter are short. The tabular vesicles become more arched, and increase in number. The minor septa and the dissepimental zone appear. The plan is, strictly speaking, tri-areal; but the outer zone is inconspicuous (Pl. V, fig. 5 *a*).

Among the forms from the northern localities, the prevalent design of the central column at this stage is that of the mature section of *A. fungites* mut. *redesdalense* (p. 69); see Pl. V, figs. 5 *a* & 6. In the more southern forms, the design usually closely approaches that of the mutation *tenbiense* (Pl. VIII, fig. 4). The design in other individuals, from both the northern and the southern areas, lies between these two types.

Fig. 7.—*(Natural size.)*



(*e*) Stage E.—The central column, the tabular vesicles, and the dissepiments are all well developed. The central column is in typical cases subquadrate in section, as well shown in Pl. V, fig. 7 *a*, and also, although not so clearly, in Pl. V, fig. 5 *b*; this is due to a slight projection at the alar fossulæ, in addition to the more prominent protuberance at the cardinal fossula. The septal lamellæ are long and numerous, but not crowded: hence a radial symmetry is characteristic of the stage. The tri-areal plan is at this stage well defined (Pl. V, fig. 5 *b*).

(*f*) Stage F.—The adult characters are now complete. The pinnate is replaced by a bilateral symmetry; the septal lamellæ are crowded, and frequently very flexuous; the column is circular, or more usually oval, in section, except for the projection into the cardinal fossula (Pl. V, fig. 5 *c*).

The above figure of the coral (fig. 7), from which sections (Pl. V, figs. 5 *a*–5 *c*) are cut at *a*..*a*, *b*..*b*, *c*..*c* respectively, is drawn of the natural size, and indicates the relative position of these stages.

VI. Structural Variations.

Unless a qualifying statement is made, the observations recorded in this section refer to the adult stages of the advanced mutations of the coral. The members of the group agree very closely in plan, but within restricted limits vary considerably in detail. Every possible variation between certain distinct types may be found. Although a certain individuality usually persists throughout any one corallum, yet, apart from ontogenetic changes, considerable variation may exist between the successive sections of the specimen.

(1) Variation of the Component Parts of the Corallum.

(*a*) The dissepiments.—A wide zone of dissepiments is an adult character, but the width attained is variable. A large corallum usually shows a proportionately wide outer area, but the relationship is not by any means a constant one. The zone may be narrow (Pl. VI, fig. 2) or broad (Pl. VII, fig. 4), of uniform width (Pl. VIII, fig. 5) or thicker at one side than another (Pl. VII, fig. 4). These dissepiments are much longer in some specimens than in others (see Pl. VI, fig. 4 *b* & Pl. VII, fig. 3 *b*), and often appear especially close-set near the inner margin of the zone in transverse sections (Pl. VII, fig. 4).

(*b*) The septa.—The septa may extend almost to the centre of the column, leaving only a narrow space between it and their ends (Pl. V, fig. 7 *b*), or in other cases they may leave a wide one (Pl. VII, fig. 5). The variations in the minor septa are not so conspicuous; but, in some cases, they project farther into the medial zone of tabular vesicles than in others. The number of septa present is in close relationship to the size of the corallum; in the large specimens figured in this paper there are over seventy major septa, but in the small form (Pl. V, fig. 9) there are only forty-eight.

(*c*) The tabular vesicles.—The tabular vesicles are strongly arched in some of the sections examined, in others they are more nearly flat. The width of the inner zone, which they occupy, does not vary so much as does that of the outer (the dissepimental) zone.

(*d*) The central column.—This, on account of its composite character, affords more scope for variation than any other part of the corallum. Its diameter ranges from about a quarter to nearly half the diameter of the corallum. In section it may appear circular or oval, corresponding to the section of the corallum, though in many cases it is more oval in form than the latter. It is always cuspidate, but this character is more pronounced in some

individuals than in others. The pericentral vesicles may be long and closely packed, or they may be shorter and loosely packed (compare Pl. VII, fig. 3 *b*, with Pl. VI, fig. 4 *b*). In instances where they are compacted and where the septal lamellæ are also crowded, the peripheral portion of the column in the horizontal section simulates the outer zone of dissepiments (Pl. VI, fig. 2) owing to the intersection of the pericentral vesicles by the lamellæ. In some cases the boundary of the central column formed by the vesicles is compact and distinct (Pl. VI, fig. 2); in others, it is loose and indefinite (Pl. VI, fig. 3).

The central vesicles are very numerous and densely packed in some specimens; in others they are less numerous, and a looser structure characterizes the column. If the septal lamellæ extend well into the column, the vesicles are much dissected (Pl. VII, fig. 3 *b*); but, if the central portion is free from lamellæ, they are more like concave tabulæ (Pl. VI, fig. 4 *b*).

The character and arrangement of the septal lamellæ, as seen in the transverse section, differ very greatly. They may be many in number or comparatively few (see Pl. VI, figs. 4 *a* & 3); but, in all cases observed, their number is greater than that of the major septa. It has already been shown that the principal lamellæ penetrate to a greater or less degree into the inner portion of the column, and many of the shorter coalesce with these. The number of minor lamellæ which unite with longer individuals, the distance from the margin at which the coalescence takes place, and the regularity with which this occurs, all produce marked differences between the transverse sections of different individuals.

(2) The Four Types of the Transverse Plan of the Central Column.

These types are:—

(*a*) The 'radial' type.—In this the principal lamellæ are relatively straight, and converge at the centre of the column (Pl. VI, figs. 1 & 2; Pl. VII, fig. 1).

(*b*) The 'tortuous' type.—In this the principal lamellæ are flexed, but nevertheless converge towards the centre as in the 'radial' type (Pl. V, figs. 5 *c* & 7 *b*; Pl. VII, fig. 4).

(*c*) The 'rose' type.—In this the principal lamellæ are short, and consequently leave the centre of the column occupied almost entirely by tabular vesicles (Pl. VI, figs. 3 & 4*a*).

(*d*) The 'retiform' type.—In this the principal lamellæ ramify irregularly over the middle of the column. This is commonest among more southern forms (Pl. VIII, figs. 1 & 2).

These designs are not sharply defined, and it is often impossible to assign a particular section to one rather than to another.

Moreover, of two sections cut from the same coral only a short distance apart, the one may approach one design and the other another.

(3) Independence of Variations in the Different Parts of the Corallum.

Each detail, as has just been shown, of coral structure is subject to considerable variation. These details vary independently of one another, except in so far as the development of one actually controls the other: as, for example, the influence of the septal lamellæ upon the central vesicles. The diameter of the central column, the intensity of its structure, the design presented by the septal lamellæ, the width of the space free from septa around the central column, and the width of the area occupied by the tabular vesicles and the dissepimental zone, all vary without any obvious connexion with each other. The result is an endless series of slightly different variations of the same general plan.

(4) Intensity[1] and Design of the Central Column considered with a view to Classification.

The central column is the most conspicuous and at the same time most variable feature of the coral, and it was mainly upon its horizontal aspect that Thomson founded his various species.

The tissue of the column (especially the septal lamellæ) affords wide scope for differentiation, as regards both intensity and design; and these two distinct lines of variation must be considered before we attempt a classification.

Intensity can have both a phylogenetic and an ontogenetic significance, and is of much more importance than the design. The adult forms from the lower part of the *Dibunophyllum* Zone (D_1) show an intensity parallel to that developed at Stage D in forms from the higher portion of the zone, D_2 and D_3. Forms are found together, in the higher horizon, which range in intensity from a stage little advanced from Stage D to the most advanced types of Stage F. This indicates failure on the part of the less specialized individuals to attain the maximum of possible development.

The design is an individual character; and, although the prevalence of a particular type often characterizes the *Aulophylla* from a certain locality or from a particular bed, forms expressing the different types are found side by side. The well-marked and recognizable types are but the extremes of variations in the several directions.

That development of the intensity and design of the central tissue is not merely a matter of time or environment, but depends also on other and unknown factors, is emphasized by the fact that marked variation in these characters may be seen in adjacent corallites of *Lonsdalia* (citing this genus merely by way of example). Mr. F. Wood-Jones draws particular attention to the enormous range of variation in the skeletons of living coral-genera existing under very slightly different conditions.[2]

[1] Intensity is here used to indicate 'crowded condition' of the tissue.
[2] 'Corals & Atolls' chapt. viii, 1910.

All things considered, the intensity of the septal lamellæ affords the most satisfactory plan of identification. It is, however, often difficult to compare individuals of different types; and, moreover, the number of lamellæ (with which intensity is really synonymous) that would appear loose in a large central column would appear denser in a smaller one.

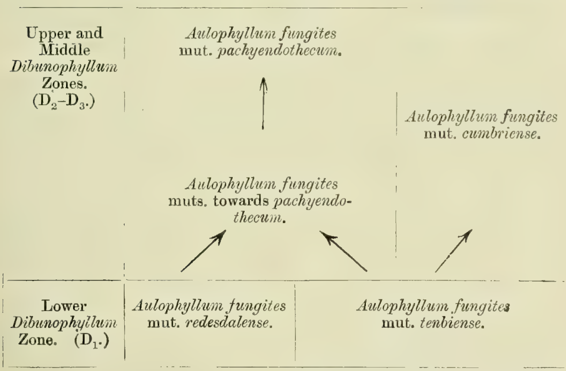
VII. Classification and Consideration of Time-Variants.

(1) Recognition of Single Species with several Mutations.

I propose to assign all the 'species' described by Thomson and others to the one species, *Aulophyllum fungites,* but recognize several mutations according to the stage of development reached.

(2) Mutations.

The mutations of the genus and the relations existing between them are arranged in the following table :—



(3) Forms from the Lower *Dibunophyllum* Zone (D_1).

Aulophyllum fungites mut. *redesdalense.*

The distinguishing characters of *A. fungites* mut. *redesdalense* are the paucity and irregularity of the principal lamellæ and the general looseness of the tissue, resulting in a loose design, of which the 'circular cells' are the most conspicuous feature (Pl. V, fig. 6). In short, the adult character of the central column is that of Stage D of *A. fungites* mut. *pachyendothecum.*

A. fungites mut. *tenbiense.*

This mutation is also distinguished by the paucity of the principal lamellæ; but these ramify over the interior of the central

column, and form with the central vesicles the retiform design seen in Pl. VIII, fig. 3. A specimen from Bristol seems to show a little advance upon the Tenby specimens, but it is too fragmentary and too ill-preserved to afford reliable information. The adult character of the central column is that of Stage D of *A. fungites* mut. *cumbriense*.

Both these early forms of *Aulophyllum* are rare.

(4) Forms from the Middle and Upper *Dibunophyllum* Zones (D_2–D_3).

A. fungites mut. *pachyendothecum* is distinguished by the great number of principal septal lamellæ. Between mutations *redesdalense* and *pachyendothecum* come a series of passage-forms equivalent to Stage E. These intermediate mutations mark a distinct stage in the phylogenetic history of the genus, but will be referred to as 'mutations towards *pachyendothecum*.'

A. fungites mut. *cumbriense* retains in the adult the retiform design of the D_1 mutation *tenbiense*, but in an intensified degree (Pl. VIII, figs. 1 & 2). This form is typical of the southern areas,[1] and I have not seen an example from the northern localities.[2] At Stage D the characters are those of mut. *tenbiense*.

From the character of the central column of Stage D (Pl. VIII, fig. 4), see pp. 64–65, it would seem in most cases that those forms which are found in northern areas were descended from mut. *redesdalense*; while the forms found in the more southern areas (all the forms of mut. *cumbriense* and many forms of *pachyendothecum*: Pl. VIII, fig. 6 *a*) had been evolved from mut. *tenbiense*. In Stage D of some individuals the character of the column is intermediate between the above-mentioned types. These may have descended from one or the other of the D_1 mutations, or possibly from some intermediate form.

One cannot always say whether the section nearest the calyx of a particular individual represents the highest stage of evolution possible for it to have attained. To prove a stage as final, it is necessary to show its persistency throughout the cylindrical portion of the corallum; this cannot be done in the case of conical and imperfect specimens.

VIII. Local Characteristics and Variations.

Although the characters of the D_2–D_3 forms have been fully treated, it still remains to survey briefly the material obtained from some of the different localities, and to remark upon one or two local types.

(*a*) Bathgate.—Much has already been said concerning the

[1] The Craven district, the country around Morecambe Bay, and the Carboniferous Limestone areas south of these localities: that is, North and South Wales, Bristol, etc.

[2] Northumberland, Durham, and North Yorkshire.

Bathgate material, and I need only emphasize the great diversity in character and the high stage of development attained by many individuals.

(*b*) Northumberland and Durham.—The forms from Northumberland and adjoining counties share these characters. The material received from the neighbourhood of Scremerston, near Berwick-upon-Tweed, mainly consisted of small forms, the central columns of which were of the 'rose' type.

From the Thornbrough Limestone near Corbridge I have collected some large forms in which the septal lamellæ, though well developed, were comparatively few in number (Pl. VII, fig. 1). At this and adjacent horizons smaller forms which closely resemble the larger forms are also abundant; but the reduced size of the central column causes the septal lamellæ to be more crowded, and hence the tissue presents a denser character (Pl. VII, fig. 2).

An interesting type is particularly characteristic of the Great Limestone of Weardale. The septa are numerous, and the outer dissepiments fine. The central column is small in comparison with the size of the corallum; but the septal lamellæ are very numerous and remarkably straight until coalescence takes place, although this does not occur until the lamellæ have passed some distance into the central column. The resultant principal lamellæ are sinuous in habit; in some cases they reach the centre of the column, in others leave clear a central space of the 'rose' type. The longitudinal section shows a dense mass of fine central vesicles and long closely-set pericentral vesicles (Pl. VII, figs. 3 *a*, 3 *b*, & 4).

The 'rose' form illustrated in Pl. VII (fig. 5) was obtained from the Great Limestone at Chollerford, near the confluence between the North and the South Tyne. It is remarkable on account of the shortness of both the major and the minor septa, the latter being very feebly developed.

(*c*) The Craven district and the country around Morecambe Bay.—The examination of the sections cut at Stage D suggests that most of the forms from these localities are descended from mut. *tenbiense* rather than from *redesdalense*. Moreover, the form described as mut. *cumbriense* retains the *tenbiense* character. Forms approaching mut. *pachyendothecum* are common, but none that I have yet examined attain the highest development of the more northern forms.

(*d*) Anglesey and North Wales.—The material from Anglesey and North Wales includes forms comparable with the Bathgate varieties (Pl. VIII, figs. 5 & 6 *b*), having long, well-developed septal lamellæ; but they usually show the *tenbiense* character at Stage D (Pl. VIII, fig. 6 *a*). Others agree more closely with mut. *cumbriense*.

(*e*) Mendip Hills.—Some specimens from the Mendip Hills appear to be little advanced upon mut. *tenbiense*; they are in too poor a state of preservation to be described with any certainty.

IX. Stereoplasmic Thickening.

The septa and vesicles are usually stouter at one part of the corallum than at another, owing to the greater development of the 'stereoplasmic' layers. At the proximal end the theca and septa are as a rule extremely thick in proportion to the size of the corallum. The septa which have originated at the cardinal fossula, even at the earliest stages, are thicker than those of alar-fossula growth (Pl. V, figs. 3 & 4), and later this distinction becomes more marked. The thickening, however, is confined to the zone of tabular vesicles, and is not continued through the outer dissepimental zone (except at the cardinal fossula). The tabular vesicles of the cardinal quadrants share the thickening, although the outer dissepiments are not usually affected, except the innermost cycle, which is often intensified to the extent of forming a boundary-wall. The microscopic structure of the thick septa does not differ from that of the thinner septa.

This greater development of stereoplasm on one side of the corallum than on the other is a normal and distinctive character of many Rugose genera.

Occasionally excessive thickening of tissue affects the whole coral or some particular part. The pericentral vesicles are, in some individuals, fused together into a thick solid wall. In a specimen from Anglesey, the tissue within the central column in the upper part of the coral was affected to such a degree by the accretion of stereoplasm, that its true nature was entirely masked. These cases indicate an abnormal condition on the part of the coral.

The tissue in well-preserved Rugose corals displays the same fibrous structure as do recent Aporosa species—fibres radiating from a medial line, but the structure has in many cases perished. In the latter case the septa and vesicles appear under the microscope as ill-defined lines in the matrix, and are crossed by the same cracks and cleavages as it is.

Pl. IX, fig. 4 represents a magnified vertical section (× 5) showing the thickened septa of cardinal-fossula origin and the unaffected alar septa in juxtaposition.

X. Rejuvenescence.

Mr. W. D. Lang,[1] in a recent paper, summarizes much that has been written on the subject of rejuvenescence, and gives a useful list of references to the observations and conclusions of previous authors. Hence only a few remarks are needed to preface this short account of the phenomenon as exhibited in a number of *Aulophylla* that I have examined.

The term was introduced by R. F. Tomes,[2] who translated

[1] 'Growth-stages in the British Species of the Coral Genus *Parasmilia*' Proc. Zool. Soc. 1909, p. 285.

[2] 'On the Madreporaria of the Inferior Oolite of the Neighbourhood of Cheltenham & Gloucester' Q. J. G. S. vol. xxxviii (1882) p. 409.

'Verjüngungsprocess' from the German of Constantin Milashevich.[1] Milashevich, in his discussion of the Aporose coral *Montlivaultia* describes (*loc. cit.*) the process as follows :—

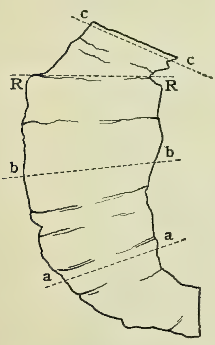
'. . . . unter gewissen, noch nicht bekannten Bedingungen der Polypenstock fast plötzlich sich einschnüren, und hierauf mehr oder weniger rasch sich wieder ausbreiten und sein Dasein in einer neuen Form fortsetzen kann.'

Tomes distinguishes rejuvenescence from calicular budding, since the latter gives birth to a number of young corallites, while the former merely produces a reduction in size (and to some extent, I may add, simplification of structure).

According to H. M. Bernard's[2] theory, rejuvenescence is the result of strobilation, or transverse fission, following which the upper individual would kill the lower one by its weight and lay down its skeleton on the old calyx. The character of rejuvenescence in *Aulophyllum* suggests the building of a newer upon an older structure, and in this respect lends support to Bernard's theory.

Dr. N. Yakovlev,[3] in a still more recent paper, makes the suggestion that the process was called into play to obviate the necessity of further expansion of the calyx. Against Yakovlev's supposition that rejuvenescence is an alternative to calicular enlargement, it may be stated that rejuvenescence as demonstrated by *Aulophyllum* may take place in young and in dwarfed individuals.

Fig. 8.—*Coral exhibiting effects of rejuvenescence. (Natural size.)*



[The specimen from which figs. 1 *a*, 1 *b*, & 1 *c* in Pl. IX, and text-fig. 9 (p. 74) were cut. 1 *a*, 1 *b*, & 1 *c* were cut at *a*...*a*, *b*...*b*, and *c*...*c* respectively.]

The following are the various structural changes observed in *Aulophyllum* :—

I. The reduction in the diameter of the central column. Attenuation commences a little below the point at which the sudden reduction in the diameter of the corallum takes place (Pl. IX, fig. 2).

II. The reduction in number of the septal lamellæ and the crowding of these within the smaller area resulting from the structural change just mentioned in I (compare Pl. IX, fig. 1 *c*, with figs. 1 *a* & 1 *b*).

III. The straightening out of the mural pericentral vesicles into an almost horizontal position, so that they become identical in character with the tabular vesicles (Pl. IX, fig. 2).

IV. A gradual reduction of the width of the zone of tabular vesicles,

[1] 'Die Korallen der Nattheimer Schichten' Palæontographica, vol. xxi (1876) pp. 194–95.

[2] Brit. Mus. Catalogue of Madreporarian Corals, vol. vi (1906) pp. 22–23.

[3] 'Die Entstehung der characteristischen Eigentümlichkeiten der Korallen Rugosa' Mém. Com. Géol. Russie, n. s. No. 66 (1910) p. 16.

commencing at the point where the reduction of the central column begins (Pl. IX, fig. 2).

V. A sudden reduction of the zone of dissepiments at a point a little farther from the proximal end of the corallum than where the changes in the central column are first observed. The result of this is a diminution in the diameter of the corallum, as shown in text-fig. 8 (p. 73) and in Pl. IX, fig. 2; also compare Pl. IX, fig. 1 *b* with 1 *c*.

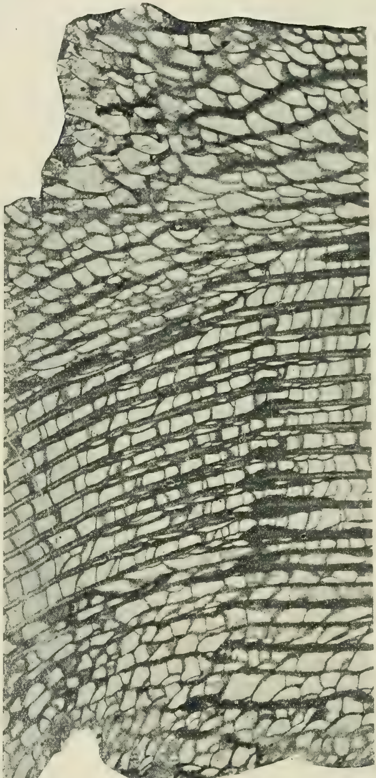


Fig. 9.—*Vertical but tangential section cut through the coral illustrated in fig. 8 through the point of rejuvenescence* R. . . R *in that figure.* (*Magnified 5 times.*)

VI. The termination of the original septa, and the formation of new septa upon their rounded edges. The latter are cemented upon the former by stereoplasm, which extends as thin irregular plates for some distance down the first-formed septa as well as up the new septa, as seen in fig. 9 (above). The extension of the cementing stereoplasm appears as thin threads at the sides of the septa.

The minor constrictions of the corallum, shown in text-fig. 1 (p. 58), which are so marked a feature in most Rugose corals, are very similar to those resulting from rejuvenescence; but they are much less pronounced. They do not appear, however, to be accompanied by any changes in the internal structure of the coral, except in the width of the dissepimental zone: unless the irregularities observed (p. 59) in the width of the central column bear some relationship to them, but this connexion is not at all obvious. Nevertheless, the contractions of the dissepimental zone probably originated from the same zone as rejuvenescence—possibly contraction on the part of the polyp itself. It may be suggested that, if the contraction of the polyp was carried beyond a certain point, it resulted in the structural changes in the corallum just described. Such extreme cases, it would seem, are comparatively rare. This suggestion is not necessarily antagonistic to Bernard's theory.

The reduction in the width of the corallum, the central column, and the dissepimental zones, and in the number of the septal lamellæ, also the straightening-out of the pericentral vesicles, recapitulate the characters of the younger stages of growth.

EXPLANATION OF PLATES V–IX.

[The sections are now preserved in the British Museum (Natural History), South Kensington.]

Plate V.

Aulophyllum fungites (Flem.). Sections illustrating ontogenesis and phylogenesis. All from Peterhill Quarry, Bathgate.

Fig. 1. Transverse section at the conclusion of Stage A. The six primary septa have been inserted; and the first two of the secondary septa are appearing at the alar fossulæ A and A′, and marking the commencement of the Zaphrentoid Stage. (C=cardinal septum; A and A′=alar fossulæ; K=counter-septum.) × 4.

2. Transverse section at the conclusion of Stage B. The separation of the septa at the centre and the presence of a rudimentary central column indicate the passage into Stage C. × 4.

3. Transverse section, Stage C, early phase. Septa penetrating the central column. Large cardinal fossula. × 4.

4. Transverse section, Stage C, later phase. Most of the septa are free from the central column, and the cardinal fossula is not so prominent as in fig. 3. × 4.

5 *a*. Transverse section, Stage D. The central column has the character of mut. *redesdalense*. × 1·5.

5 *b*. Transverse section, Stage E. × 1·5.

5 *c*. Transverse section, Stage F, showing the characters of mut. *pachyendothecum*. × 1·5.

6. Transverse section, mut. *redesdalense*. Fourlaws Limestone, Waterfalls Quarry, near Redesdale (Northumberland). × 1·5.

7 *b*. Transverse section, 'tortuous' type. Mut. *pachyendothecum*.

7 *a*. Earlier transverse section of the same individual at Stage E, showing the subquadrate aspect of the central column.

Figs. 8 & 9. Transverse sections, mut. *pachyendothecum*, showing different rates of growth. Fig. 8 is cut at 5 cms. and Fig. 9 at 8 cms. from the proximal end of the coral. Both figures are of the natural size.

Plate VI.

Aulophyllum fungites (Flem.). Sections illustrating the variability of the species. All from Peterhill Quarry, Bathgate. [The magnification in every case is 1·5.]

Fig. 1. Transverse section, 'radial' type. Mut. towards *pachyendothecum.*
2. Transverse section, 'radial' type. Mut. *pachyendothecum.*
3. Transverse section, 'rose' type. Mut. towards *pachyendothecum.*
4 *a*. Transverse section, 'rose' type. Mut. *pachyendothecum.*
4 *b*. Vertical section of the last-figured specimen. The section passes through the middle of the central column in the upper part of the coral, but approaches the margin of the same in the lower part. Contrast this figure with Pl. VII, fig. 3 *b*.

Plate VII.

Aulophyllum fungites (Flem.). Forms from Northumberland and Durham. [The magnification in every case is 1·5.]

Fig. 1. Transverse section. Mut. towards *pachyendothecum,* but little advanced upon Stage E. Central column of the 'radial' type. Thornbrough Limestone, Thornbrough Quarry, near Corbridge (Northumberland).
2. Transverse section. Mut. towards *pachyendothecum.* Small variety from the Thornbrough Limestone, Stanton (Northumberland). Apparently a dwarfed form of fig. 1.
3 *a*. Transverse section of a smaller example of fig. 4. Columella of the 'rose' type.
3 *b*. Vertical section of fig. 3 *a*. Note the numerous and compacted vesicles in the central column and the small regular outer dissepiments.
4. Transverse section. Mut. *pachyendothecum.* A variety especially characteristic of the Great Limestone, Weardale (County Durham). Also common in other beds in the Weardale and Alston district. Note the small but densely-packed central column. From the Great Limestone, Stanhope-in-Weardale.
5. Transverse section. Mut. towards *pachyendothecum,* showing a 'rose' type, and a very wide space between the ends of the septa and the central column. Great Limestone, Black Pasture Quarry, near Chollerford (Northumberland).

Plate VIII.

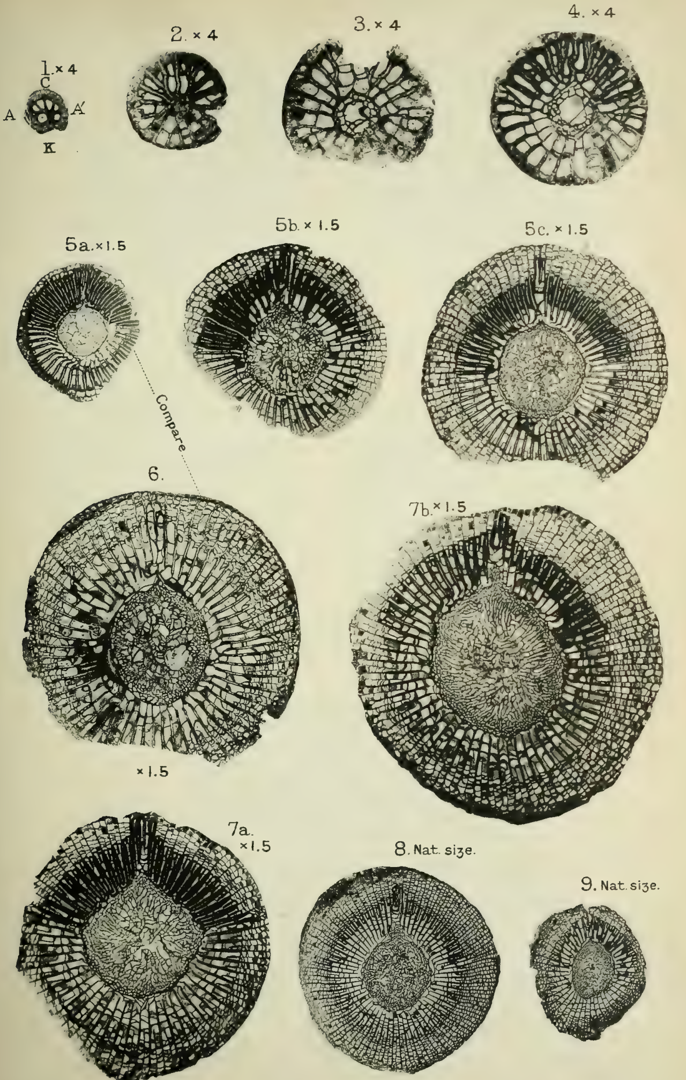
Aulophyllum fungites (Flem.). Forms from Cumberland and Wales. [The magnification in every case is 1·5.]

Figs. 1 & 2. Transverse sections. Mut. *cumbriense,* Humphrey Head (Morecambe Bay).
Fig. 3. Transverse section. Mut. *tenbiense,* Lydstep (Tenby).
4. Transverse section of another specimen from Humphrey Head, cut through Stage D, showing the characters of mut. *tenbiense.*
5. Transverse section. Mut. towards *pachyendothecum,* not much advanced upon Stage D; variety from Gleaston, near Barrow-in-Furness.
6 *a*. Transverse section of the last at Stage D, showing characters similar to those of mut. *tenbiense.*
6 *b*. Transverse section. Mut. near *pachyendothecum.* Craignant, near Oswestry.

Plate IX.

Aulophyllum fungites (Flem.). Sections illustrating rejuvenescence, etc.

Figs. 1 *a*–1 *c*. Transverse sections of a coral displaying rejuvenescence; 1 *a* & 1 *b* are cut below the point of rejuvenescence, and 1 *c* about that point (at *a*, *b*, & *c* in text-fig. 8, p. 73). × 1·5.
Fig. 2. Vertical section of another coral showing the same phenomena. × 1·5.

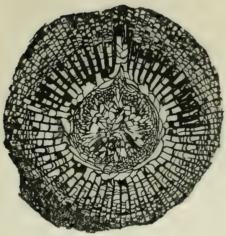


W. Tams, Photo.

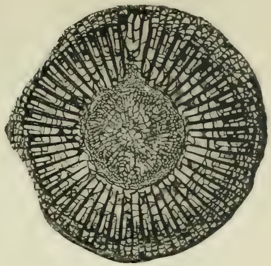
Bemrose, Collo., Derby.

AULOPHYLLUM.

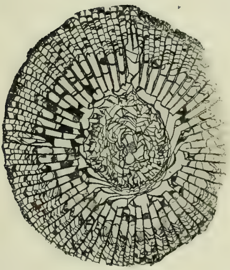
1.



2.



3.



4a.

4b.

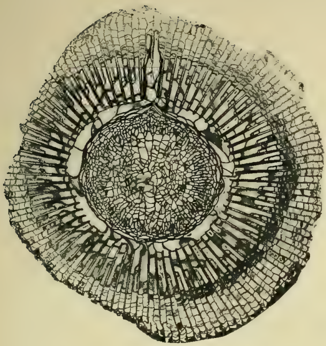
W. Tams, Photo.

Bemrose, Collo., Derby.

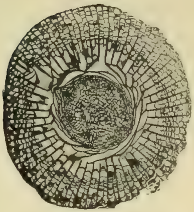
AULOPHYLLUM.

[All figures magnified by 1.5.]

1.

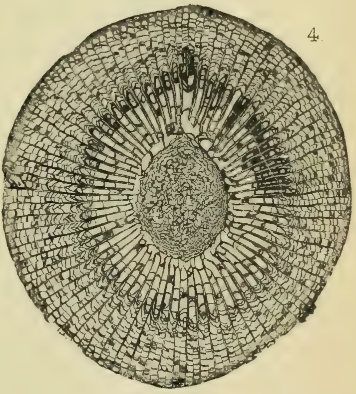


2.



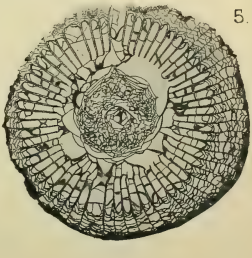
3a.

4.



3b.

5.



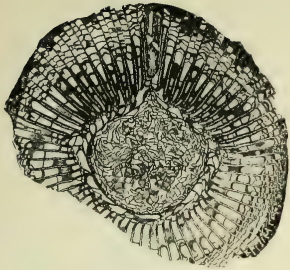
W. Tams, Photo.

Bemrose, Collo., Derby.

AULOPHYLLUM.

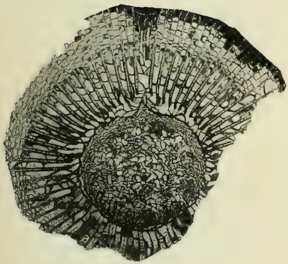
[All figures magnified by 1.5.]

1.

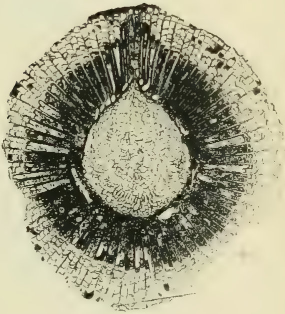


5

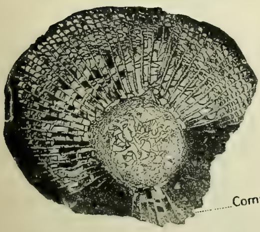
2



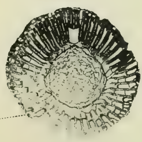
6b.



3.

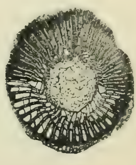


4.



Compare

6a.

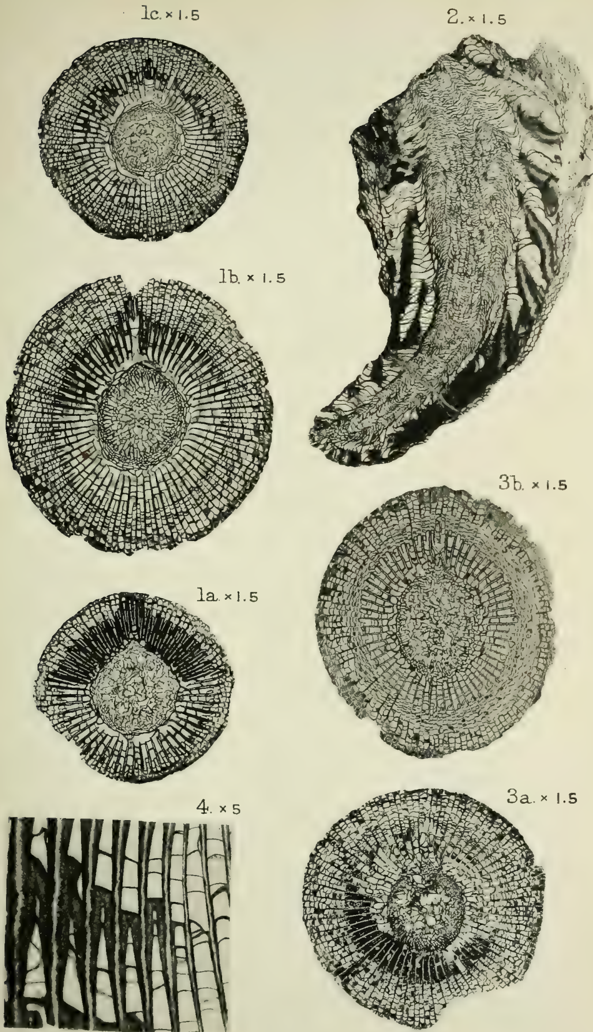


W. Tams, Photo.

Bemrose, Collo., Derby.

AULOPHYLLUM.

[All figures magnified by 1.5.]



W. Tams, Photo.

Bemrose, Collo., Derby.

AULOPHYLLUM.

Figs. 3 *a* & 3 *b*. Transverse sections of a third specimen in which rejuvenescence has taken place. Fig. 3 *b* is cut through the point corresponding to R . . R in text-fig. 8 (p. 73), and 3 *a* is cut about 3 mm. below that point. Between 3 *a* and 3 *b* considerable reduction, both in number and in length of the septal lamellæ, has taken place. × 1·5.

Section illustrating stereoplasmic thickening.

Fig. 4. Vertical section through septa, showing the stereoplasmic thickening of the septa and dissepiments in the cardinal quadrant. × 5.

All from Peterhill Quarry, Bathgate.

Discussion.

Dr. A. Vaughan complimented the Author upon the detailed manner in which he had studied a group of highly-specialized Clisiophyllids, and felt sure that the paper would assist materially in the elucidation of many obscure points in coral-development. From the excellent figures shown by the Author it appeared that, as soon as any definite septal plan could be asserted, the coral already possessed the essential characters of the genus. He thought that the conspicuous irregularity of the very earliest stages might equally well be attributed to imperfect reminiscence of ancestral characters, or to mere youthful plasticity; and he considered that a great number of *Aulophylla* must be cut through their earliest stages before the truth is arrived at. With regard to the structure of the coral, from the fact that the tabulæ rise at the *Aulophyllum* wall, he thought that it would be impossible to demonstrate the continuity of the septa across that wall by horizontal sections alone. He considered that the structures shown in one figure, and said to illustrate rejuvenescence, might be explained as a case of breakage followed by subsequent mending. Finally, he enquired whether the *Aulophylla* could be employed to determine levels within the Yoredalian, which was a long period and had as yet resisted faunal subdivision.

The Author, in reply, stated that he was able to recognize forms from D_1 as distinct from those which were found in the Upper *Dibunophyllum* Zone, but could not differentiate between those characteristic of D_2 and D_3; hence he was unable to use them for the purpose of subdividing the Yoredales. He wished to point out that he termed the stage of development B, the 'Zaphrentoid Stage' and not '*Zaphrentis* Stage,' and said that he had not found any stage which corresponded to *Cyathophyllum*. He was certain, however, that the septa entered the central column in Stage C.

With regard to Dr. Vaughan's question concerning the possibility of the corallum having been broken and then repaired, he thought that the evidence pointed more strongly to the erection of a newer upon an older structure.

In conclusion, he expressed his obligations to all those who had so generously placed material at his disposal, and also thanked the many friends who had aided him with information and suggestions, especially Mr. R. G. Carruthers, Mr. W. D. Lang, and Dr. A. Vaughan.

6. NOTES *on the* DISCOVERY *of* FOSSILIFEROUS OLD RED SANDSTONE ROCKS *in a* BORING *at* SOUTHALL, *near* EALING. By ERNEST PROCTOR, A.R.C.S. (Communicated by Prof. W. W. WATTS, Sc.D., F.R.S., V.P.G.S. Read November 6th, 1912.)

Introduction.

IN 1911 my attention was called to a boring at the works of Messrs. Otto Monsted & Co. at Southall. The work was carried out by Messrs. Isler & Co., and I wish to express my indebtedness to the firms in question for the facilities granted for the examination of cores, and for permission to publish my conclusions thereon. The examination of the rocks was carried out in the Geological Laboratories of the Imperial College of Science & Technology, and the determination of the bulk of the fish-remains was made by Dr. A. Smith Woodward, who has added an appendix on them to this paper. I am also indebted to Dr. D. H. Scott and to Mr. A. J. Maslen for examining certain problematical fossils, which are probably of vegetable origin.

Southall is on the Great Western Railway, about midway between Paddington and Windsor. The position of Messrs. Otto Monsted & Co.'s factory is about 100 yards south of Southall Station (G.W.R.). The purpose of the well was to obtain water from the Lower Greensand, which had been struck and yielded copious supplies of water at Slough, 9 or 10 miles farther west. As will be seen, the well was a failure from this point of view, as the boring passed from the Gault directly into Palæozoic rocks. But to the geologist the result is of considerable interest, because of the new light thrown by it on the age of the Palæozoic rocks of the London area.

Particular reference is made in this paper to Prof. Judd's memoir 'On the Nature & Relations of the Jurassic Deposits which underlie London.'[1] Copious references to the literature, as well as an admirable summary of the conclusions reached, are to be found in Mr. Whitaker's 'Geology of London' Mem. Geol. Surv. (1889). In the 'Report of the Royal Commission on Coal-Supplies'[2] Dr. A. Strahan & Prof. O. T. Jones give a table and map (Appendix iv) of 'the more important borings, throwing light on the possible occurrence of concealed coalfields,' with references to published accounts. It is, therefore, needless to go any further into the bibliography of deep borings.

[1] Q. J. G. S. vol. xl (1884) p. 724.
[2] Final Report, pt. ix (1905) pp. 36–45.

The Tertiary and Secondary Rocks.

Unfortunately, my attention was not called to the boring until Palæozoic rocks had been reached, and all the cores of the superincumbent rocks had been removed. Messrs. Isler, however, have kindly supplied a record of the rocks passed through, and also allowed me to examine small samples of the cores kept by them. In the absence of fossils it is, of course, impossible to draw the exact limits of the various formations passed through. The engineer's record is therefore printed in the sequel, and approximate lines of demarcation are drawn on the evidence that exists.

Mr. Mears, the engineer, informed me that there was only about 6 inches of what might represent the Upper Greensand; while, from my own observation, I can confirm the entire absence of the Lower Greensand. The Gault, with a layer of phosphatic nodules at its base, rested directly upon the red rocks to be immediately described. As the thickness of Chalk given in the journal is about 100 feet less than at the Richmond boring, it is practically certain that some of the rock marked 'Blue Gault' is in reality part of the Chalk.

The Palæozoic Rocks.

These rocks were struck at a depth of 1130 feet, and continued with slight variations down to 1261 feet, the final depth of the boring. There is so close a resemblance between them and the 'red rocks' of the Richmond borehole that Prof. Judd's description of the latter holds for the former. They consist of red and green mottled clays and sandstones, with occasional bands of fine conglomerate. Mica is a very abundant constituent; particles of galena occur; and, upon microscopic examination, minute rhombohedra of dolomite proved to be fairly abundant.

Large quantities of the core were broken up, with the result that fossils were found. These were present in a marked type of rock, which occurs in bands varying from about 1 inch to an eighth of an inch in thickness. It consists almost wholly of organic remains, associated with rounded and subangular pebbles of quartz.

The principal fossils are the remains of fishes, which are fortunately preserved in sufficient perfection to enable Dr. Smith Woodward to make generic determinations of them. They consist of scales and teeth of *Holoptychius*, and plates of *Bothriolepis*. Both these genera are characteristic of the Upper Devonian or Old Red Sandstone. The appendix by Dr. Smith Woodward (p. 81) gives a description of the more important of these remains.

Other fossils were found, but for the most part they are of too fragmentary a nature for determination. In the microscopic slides, however, minute bodies which are probably plant-remains are to be seen. These were submitted to Dr. D. H. Scott and Mr. A. J. Maslen. Dr. Scott remarks that they are unlike any Devonian plants with which he is acquainted, and suggests that

some of them may be sections of calcareous algæ built up of a number of fine tubes. Calcareous *Siphoniæ* are certainly known from as far back as the Devonian Period.

Record of Rocks passed through.

The record of the boring given by Messrs. Isler is as follows :—

		Thickness in feet.	*Depth in feet.*
Made ground and alluvium.	Brown clay	6	6
	Gravel and sand	20	26
	Brown clay	1	27
London Clay ...	Blue clay	196	223
Lower London Tertiaries, including Thanet Sands.	Black pebbles	1	224
	Mottled clay	16	240
	Yellow mottled clay	10	250
	Mottled clay and pebbles	12	262
	Sandy mottled clay	22	284
	Dark sandy clay	3	287
	Loamy green sand	8	295
Chalk	Chalk	107	402
	Grey chalk	466	868
Gault	Blue Gault	262	1130
Devonian	Red marl	97	1227

[This record would appear to have been made when the boring had only reached 1227 feet. A record of the boring, with a slight variation in the figures for the Chalk and Gault, has been published by the Geological Survey since the reading of this paper: see 'Records of London Wells' Mem. Geol. Surv. 1913.]

Conclusions.

(1) The absence of anything corresponding to the Lower Greensand might perhaps have been anticipated. In his Presidential Address to the Geological Society in 1900[1] Mr. W. Whitaker pointed out that, while this formation is present in all the borings east of the River Darent in Kent, it is thinning towards the west. It is present at Crossness, and is only 10 feet thick at Richmond. As the Lower Greensand is absent at Southall, it appears strange that it is present at Slough in sufficient thickness to yield large quantities of water.

In this connexion, it is interesting to notice that Sir Joseph Prestwich[2] held the view that the old Palæozoic land was of the nature of a ridge, with breaks in it at intervals. He wrote :—

'I cannot imagine but that, from the very peculiar mineral character of the mass in Bedfordshire and Surrey, there must have been, in places, continuity between these areas, and I therefore infer that the Lower Greensand may yet be found under the Chalk at many places, and that, although not immediately under the north of London, it yet will be found at no great distance both to the north and south of that spot.'

[1] Q. J. G. S. vol. lvi (1900) pp. lxxviii–lxxix.
[2] *Ibid.* vol. xiv (1858) pp. 251–52.

The presence of the Lower Greensand at Slough seems to indicate that here we have a break, perhaps of the nature of a bay or other inlet, into the Palæozoic land. On the other hand, it may be that the Palæozoic mass, instead of continuing in an east-and-west direction as generally assumed, may here swing round to the north and join up with the Charnian axis.

(2) The determination of the 'red rocks' at Southall as undoubtedly of Old Red Sandstone age throws new light on similar rocks recorded from other localities in the London district. In the absence of fossils, all the evidence brought forward by Prof. Judd for the post-Carboniferous age of the 'red rocks' of the Richmond boring would apply equally to the Southall rocks; and this conclusion would have been strengthened by the discovery of dolomite rhombs from the latter locality, an occurrence hitherto best known from Keuper beds. As no fossils were found at Richmond, Crossness, or Kentish Town, Prof. Judd was driven to make the utmost of a careful lithological comparison with both Old Red and New Red rocks, on the Continent as well as in this country. The result of this comparison, confirmed by eminent foreign geologists, was that there seemed to be a closer resemblance to post-Carboniferous than to pre-Carboniferous rocks. Prestwich, however, preferred to consider that the 'red rocks' were of Devonian age, and many later geologists have consistently spoken of them as Old Red Sandstone, despite the difficulty created by the presence of undoubtedly marine Devonian rocks in other borings under London. Thus in the Royal Coal Commission's Report, already cited, these rocks are referred to as 'Old Red Sandstone?' or '[Old Red Sandstone?].' But such determinations always failed to command complete confidence, because of the want of palæontological evidence. Now that all doubt is removed in this one instance, it may very well be considered that the rest of the 'red rocks' are also of Old Red Sandstone age.

(3) The occurrence of particles of galena in both the Southall and the Richmond rocks, together with the occurrence of dolomite crystals in the former and sodium chloride in the latter, indicate that the waters in which they were deposited were fairly concentrated. Again, the Southall rocks bear little resemblance to the undoubted Devonian rocks from the Tottenham-Court Road and Turnford borings, nor have they yielded any of the marine fossils found at the other two localities.

APPENDIX.—NOTE *on the* FISH-REMAINS *from the* UPPER DEVONIAN.

By ARTHUR SMITH WOODWARD, LL.D., F.R.S., F.L.S., Sec.G.S.

[PLATE X.]

THE red sandy clay contains abundant fragments of the bony dermal armour of fishes, but most of these are too small for determination. When examined with an ordinary lens, a few

smooth granular pieces appear to resemble the tubercles of *Thelodus*; but in section under the microscope all the specimens distinctly exhibit bone-cells, and so belong only to higher types of fishes. In all cases the bone-cells occur between parallel laminæ, not arranged in haversian systems, the bony tissue being thus of the primitive type described by Pander as isopedin. A few fragments are larger than the others, and among these, as already recognized by Mr. Proctor, there are characteristic remains of *Holoptychius* and *Bothriolepis*.

One elongate ovoid scale nearly 3 cm. in length (Pl. X, fig. 1) shows in impression the typical external ornament of *Holoptychius*. The longitudinal ridges are large and few, thick and rounded as in *H. nobilissimus*, not so thin and sharp as in *H. flemingi*. They are rarely bifurcated and intercalated, and none are subdivided into tubercles. Their arrangement corresponds closely with that of the ridges on some ventral caudal scales in the type-specimen of *H. nobilissimus* from Clashbennie (Perthshire). Part of the inner face of the same scale is preserved, exhibiting a peculiar pitted and reticulated structure, which is seen again on the inner face of a second scale of smaller size and more nearly circular shape (Pl. X, fig. 2). It may also be added that two or three fragments in microscope-sections of the rock display the curious chevron-pattern formed by the constituent laminæ, which has already been observed by M. Lohest[1] in a section of a thick scale of *Holoptychius* from the Devonian of Belgium.

Part of the impression of a Holoptychian tooth, about 1 cm. in height, bears marks of its fine longitudinal ridges, with the intercalated more delicate ridges, extending nearly to the smooth blunt apex. Mr. Proctor made a transverse section of part of this tooth, and observed its dendrodont structure; but the specimen was unfortunately too fragile for preservation.

Two portions of dermal plates clearly belong to *Bothriolepis*, as shown by their pitted external ornament and their cancellous structure (Pl. X, fig. 3). Equally thick plates of *Holoptychius* would be densely laminated, without any conspicuous cavities. In one specimen the superficial pits are smaller and more sharply defined than in the other, but similar variations may be noticed in different parts of the shield of one and the same species of this genus.

An internal impression of another piece of dermal armour also seems to be referable to *Bothriolepis*, and may almost certainly be interpreted as a right posterior ventro-lateral plate. It is bent along its longer axis at an angle somewhat greater than a right angle; and the margin of the excavated hinder end shows the impression of a wide rounded thickening on the inner face, which would strengthen this part. Traces of the bone itself are seen, and they bear the characteristic pitted ornament.

[1] Ann. Soc. Géol. Belg. vol. xv (1888) Mém. p. 128 & pl. ii, fig. 4.

Fig. 1. × 3 diameters.

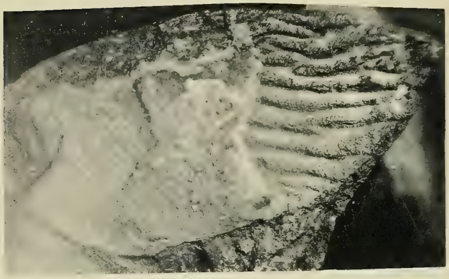


Fig. 2. × 3 diameters.

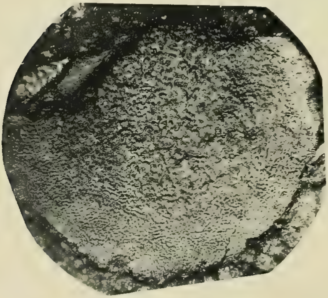


Fig. 3. × 3 diameters.

E. Proctor, Photo.

Bemrose, Collo., Derby.

HOLOPTYCHIUS & BOTHRIOLEPIS
from the SOUTHALL Boring.

Holoptychius and *Bothriolepis* occur together in the Upper Old Red Sandstone of Morayshire and Fifeshire; in a corresponding formation north of St. Petersburg (Russia); and in the Catskill Formation of Pennsylvania (U.S.A.). *Holoptychius* is also met with in the Upper Devonian of Belgium, while *Bothriolepis* is known from a yellow sandstone just below the Carboniferous Limestone of Farlow (Shropshire). The remains found in the red sandstone in the Southall boring, therefore, although so fragmentary, are enough to indicate its Upper Devonian or Upper Old Red Sandstone age.

EXPLANATION OF PLATE X.

[All the figures are magnified 3 diameters.]

Fig. 1. Scale of *Holoptychius* sp., from within, the exposed portion shown in impression on the matrix.

2. Scale of *Holoptychius* sp., inner face.

3. Dermal plate of *Bothriolepis* sp., the ornament shown in impression on the matrix.

Discussion.

The President (Dr. A. Strahan) commented on the difficulty of the search for fossils which had been brought to so successful an issue by the Author. He had himself always been of opinion that the red strata present in the borings at Richmond, Streatham, Crossness, Willesden, Chiswick, and Southall were of Old Red Sandstone age, and had so classed them in the table of borings published by the Royal Commission on Coal-Supplies. This, however, was merely an opinion, founded on a lithological resemblance with the rocks of South Wales. The definite proof of the existence at Southall of those upper beds of the Old Red Sandstone which pass up into the Carboniferous was of great value.

Dr. J. W. Evans congratulated the Author on the excellent use that he had made of the opportunity afforded by the boring, which he only heard of by a happy chance. He suggested that the law should require that full information with regard to borings should be given to the Geological Survey.

He thought that the association of Old Red Sandstone and Devonian types could hardly be described as a new fact in the geology of this country. It occurred in the South of Ireland, in Pembrokeshire, and, above all, in North Devon, where three separate occurrences of typical Old Red Sandstone were succeeded by marine Devonian. The two are also associated in the Psammites de Condroz in Belgium, where some beds contain *Holoptychius* and *Asterolepis*, and others a fauna allied to that of the Lower Pilton Beds. The Southall cores were compared with the Pickwell-Down Sandstone, in which obscure fish-remains have been found; and it was suggested that they were probably younger than the Frasnian of the Tottenham-Court Road boring and older than the cores of the Turnford bore, which contained a Lower Pilton fauna.

An important feature of the Devonian rocks below the Thames Valley was that all the three fossiliferous localities were of Upper Devonian age: this might have been expected. The Upper Devonian rocks of West Somerset were believed by the speaker to overlap the Devonian rocks below them, and in the Mendips and at Tortworth the Upper Old Red Sandstone rested on the Silurian; while in the Bassin de Namur and the Boulonnais the *Stringocephalus* Beds at the summit of the Middle Devonian, succeeded by the Upper Devonian, rested with a conglomeratic base on much older rocks.

He also alluded to the serious loss that geologists would suffer from the substitution of the chisel-drill for the diamond-drill, which appeared probable in borings for water and other purposes.

Dr. H. Lapworth said that the suggestion of the previous speaker, that records of all British borings should be lodged at the Geological Survey Office, was a good one; but it would be necessary to carry the matter a good deal farther than this, if the records were to be depended upon. The journals of borings were kept by men who were often more or less uneducated, and possessed little or no knowledge of geology. In his own experience he had found that such records were not satisfactory. A Government control of boring records could only be efficiently maintained if the Geological Survey were notified before every boring was begun, in order that the journal should be made under geological supervision. The occasional use of the chisel in the process of boring was to be regretted by geologists; but the borer himself was concerned solely with the cost, and in cases where cores are not demanded, the chisel, being cheaper in many materials than the rotary processes, was often largely employed.

Mr. C. E. N. Bromehead remarked that, according to Messrs. Isler's account, the Gault was divided into two parts, the upper 125 feet [should be 121] being separated from the remainder by beds of sand. The suggestion was that this sand was Upper Greensand, and the upper part of the 'Gault' part of the Chalk. The total thickness of Chalk then amounted to 700 feet [should be 702]. It was most important that geologists should see the cores, and not be dependent on the well-sinkers' accounts, which were a fruitful cause of scientific immorality. On *a priori* grounds he would have expected at least 700 feet of Chalk at Southall; he therefore interpreted Messrs. Isler's record in the light of a theory, and quoted the resultant reading as evidence in support of that theory.

7. A Contribution *to our* Knowledge *of* Wealden Floras, *with especial reference to a* Collection *of* Plants *from* Sussex. By Albert Charles Seward, F.R.S., F.G.S., Professor of Botany in the University of Cambridge. (Read November 6th, 1912.)

[Plates XI–XIV.]

I. Introductory Remarks.

In November of last year (1911) Mr. Charles Dawson, F.S.A., F.G.S., submitted to me for examination a small collection of plants obtained by him, with the able assistance of Father Teilhard de Chardin and Father Félix Pelletier, from the Wealden Beds of Sussex, for the most part from the neighbourhood of Fairlight. Several of the specimens, although specifically identical with previously recorded types, are better preserved or larger than any hitherto found, and furnish new facts of importance. The collection includes also several new species. In accordance with Mr. Dawson's wish, the specimens have been handed to Dr. Smith Woodward as a gift to the Geological Department of the British Museum (Natural History). With the exception of the example of *Sagenopteris mantelli* shown in Pl. XI, fig. 3, which is from the Ashdown Sands, the fossils in the Dawson Collection were obtained from the Fairlight Clay.

In the descriptive section of this paper are included a few specimens from the Rufford Collection (collected at Ecclesbourne, near Hastings), acquired by the Museum subsequent to the publication of the Catalogue of Wealden Plants.[1]

II. Description of the Specimens.

EQUISETALES.

Equisetites lyelli (Mant.). (Pl. XI, figs. 1 *a* & 1 *b*.)

(Near Fairlight, Wadhurst Clay; Dawson Collection.)

1833. Mantell, 'Geology of the South-East of England' p. 245 & figs. 1–3.

The specimen represented in Pl. XI, fig. 1 *a*, though smaller than some previously figured from the Wealden Beds of Sussex, exhibits certain features worthy of notice. The incomplete internode has a length of 4 cm. and a breadth of 7 mm. A portion of a leaf-sheath is seen at the upper end with linear lanceolate teeth (fig. 1 *b*) showing a ragged carbonized border, which may be the remains of torn, transversely elongated cells, such as form the commissural tissue in the leaf-sheaths of recent species. On the linear divisions of the sheath and on the free acuminate teeth the outlines

[1] Seward (94) & (95). These numerals in parentheses refer to the Bibliography, § IV, pp. 112–15.

of elongated rectangular cells are clearly preserved (Pl. XI, fig. 1 *b*). The internode is longer than in previously-recorded specimens referred to this species.

In its slender dimensions, and in the form of the leaf-sheath, the fossil agrees generally with Mantell's species; but it differs in the greater elongation of the internode from the majority of specimens recorded from America,[1] Germany,[2] and elsewhere. It is essentially similar in form to the shoots of existing members of the genus, and of narrower diameter than the common Jurassic species, *Equisetites columnaris* Brongn. A very similar type is represented by *E. virginicum* Font.,[3] which Mr. Berry believes to be identical with Dunker's species, *E. burchardti*: while expressing some doubt as to the correctness of this view, I must admit that the line of demarcation between *E. lyelli* and *E. burchardti* is not very clearly defined.

Some specimens described by Dr. Neumann[4] from Peru as *E. lyelli*, whether or not correctly determined, appear to be of the same general type as that species.

LYCOPODIALES.

LYCOPODITES TEILHARDI, sp. nov. (Pl. XI, figs. 2 *a* & 2 *b*.)
(Fairlight Clay, Fairlight; Dawson Coll.)

The fragment shown in fig. 2 *a* consists of a slender forked axis bearing two rows of alternate oval leaves, 8 mm. long, with a median vein. Superposed on the axis there appears to be a row of rather smaller leaves, a few of which are seen in fig. 2 *b*. The faint stain on the rock made by the short and broad leaves suggests comparison with the thin lamina of many species of *Selaginella*, and the apparent occurrence of dimorphic foliage points in the same direction.

Despite the probability that the specimen is more closely related to *Selaginella* than to the genus *Lycopodium*, the generic name *Lycopodites* is adopted in preference to *Selaginellites*, in conformity with Prof. Zeiller's suggestion[5] that the latter designation should be reserved for plants in which heterospory has been demonstrated.

An American species, originally recorded by Fontaine[6] and more recently described by Mr. Berry[7] from the Patapsco Formation (Potomac) of Maryland as *Selaginella marylandica*, agrees closely with *L. teilhardi*, except in the absence of any indication of heterophylly.

[1] Berry (11^2) p. 311 & pl. xli, figs. 7–8.
[2] Schenk (71) p. 207 & pl. xxii, figs. 10–13.
[3] Fontaine (89) pls. i & ii; Berry (11^2) p. 310.
[4] Neumann (07) p. 77, & pl. i, fig. 2.
[5] Zeiller (06) p. 141.
[6] Fontaine in Ward (05) pl. cxv, figs. 9 & 10.
[7] Berry (11^2) p. 307 & pl. xli, figs. 1–2.

SELAGINELLITES DAWSONI, sp. nov. (Text-fig. 1, below.)
(Fairlight Clay, Ecclesbourne; Rufford Coll.)

The specimen on which this species is founded occurs on a piece of ironstone, in close association with a sterile repeatedly-branched shoot, identical with the impression represented in pl. i, fig. 8, of the first part of the 'Wealden Flora',[1] and described as *Planta incertæ sedis*. The fertile shoot consists of a ribbon-like axis 3 cm. long and approximately 2 mm. broad: at the edges of the axis are faint broadly-triangular impressions of sporophylls, and the median region bears numerous spherical sporangia. From the sporangia both megaspores and microspores have been obtained in an exceptionally good state of preservation: the spores have a tuberculate outer wall. The microspores, which often occur in tetrads, are approximately ·04 mm., and the megaspores ·35 mm., in diameter. Both spores closely resemble those of some recent species of *Selaginella*. In addition to the larger piece of fertile axis there is another fragment, the lower part of which is sterile and identical with the vegetative shoot previously figured.[2] The discovery of the spores, while confirming the former comparison of the sterile specimen with a lycopodiaceous plant, demonstrates a closer affinity to *Selaginella* than to *Lycopodium*.

Fig. 1.—Selaginellites dawsoni, *sp. nov.* *(natural size).*

It is proposed to publish an illustrated account of this species, which I have named after Mr. Charles Dawson, whose labours have materially added to our knowledge of the Wealden flora, in a forthcoming number of the 'New Phytologist.'

FILICALES.

? HYDROPTERIDEÆ.

SAGENOPTERIS MANTELLI (Dunk.). (Pl. XI, figs. 3 & 5.)
(Ashdown Sands, near Fairlight; Dawson Coll.)

1846. W. Dunker, 'Monographie der Norddeutschen Wealdenbildung' p. 10 & pl. ix, figs. 4–5.

The British specimens of this species previously figured are rather smaller than those in the Dawson Collection. Fig. 5 shows portions of two relatively broad leaflets, with clearly-preserved anastomosing veins and a fairly definite midrib in the proximal part of the lamina, attached to a common petiole. Some of the leaflets figured by Dunker are identical in form with the Fairlight specimens, and similar examples occur in the Rufford Collection

[1] Seward (94) p. 20. [2] Seward (94) pl. i, fig. 8.

(Natural History Museum). The fact that in the Jurassic species *Sagenopteris phillipsi* (Brongn.) there is clear evidence of considerable variation in the size of the leaflets and in the extent and distinctness of the midrib, lends support to the view that a similar variability characterizes the Wealden type, of which there is less available material. In all probability, the larger leaflet shown in Pl. XI, fig. 3, which reached, when complete, a length of 7 cm. and has a much more distinct midrib than the shorter leaflets, is not specifically distinct from the example represented in fig. 5 of the same plate. The long and narrow meshes formed by the anastomosing veins are approximately 0·7 mm. in breadth.

The close agreement between *S. mantelli* and *S. phillipsi* is such as to render impossible a satisfactory separation in all cases; but, having regard to the average form of the leaflets, it would seem that in *S. mantelli* the lamina is usually shorter and broader than in the older form. A comparison of some specimens, recently described from the Kimmeridge Beds of Sutherland [1] as *S. phillipsi*, with that represented in Pl. XI, fig. 3 illustrates the difficulty of accurate determination.

The specimens described by Fontaine and Berry [2] as *S. elliptica* from the Potomac Group, and compared by the latter with *S. mantelli*, agree very closely with the leaflet shown in fig. 3. The examples figured by Fontaine as *S. elliptica*,[3] from the Shasta Formation of California, are in all probability referable to *S. mantelli*. The imperfect fossils from South-Eastern Scania, probably of Middle Liassic age, compared by Dr. Halle [4] with *S. mantelli*, are too incomplete to be referred to that type with any degree of certainty.

SAGENOPTERIS ACUTIFOLIA Sew. (Pl. XI, fig. 4.)

(Ecclesbourne, Rufford Coll.)

1895. A. C. Seward, 'Wealden Flora' pt. 2, p. 225.

The narrow leaflet represented in fig. 4 is characterized by a distinct midrib; the lateral veins are obscure, but there are indications of anastomosis. This specimen is similar in size and shape to one from the Hastings neighbourhood originally described as *Phyllopteris acutifolia*,[5] and afterwards, as the result of a re-examination of the impression, referred to the genus *Sagenopteris*.

These narrow leaflets resemble the smaller forms of *S. undulata* Nath.,[6] and are very similar to some of the specimens from Sutherland included in *S. phillipsi*.[7] It is by no means unlikely that the leaflet reproduced in Pl. XI, fig. 4 is specifically identical with the large examples shown in figs. 3 & 5 of the same plate.

[1] Seward (11) pl. i, fig. 1.
[2] Berry (11^2) pp. 287–89.
[3] Fontaine in Ward (05) p. 236 & pl. lxv, figs. 39–40.
[4] Halle (10) p. 8 & pl. i, figs. 18–21.
[5] Seward (94) p. 143 & pl. ix, fig. 6.
[6] Halle (10) pl. i, fig. 3.
[7] Seward (11) p. 656 & pl. i, fig. 4.

EUFILICINEÆ.

Matonineæ.

MATONIDIUM GŒPPERTI (Ett.). (Pl. XIV, fig. 3 *a*; text-fig. 2 C, p. 91.)

(Fairlight, Dawson Coll.)

1843. *Cycadites althausii* Dunker, Progr. d. h. Gewerbsch. Cassel, p. 7.
1852. *Alethopteris gœpperti* Ettingshausen, Abh. k.-k. Geol. Reichsanst. vol. i, pt. 3, No. 2, p. 16 & pl. v.

The older specific name *althausii* has been revived by Lester Ward,[1] and this unfamiliar designation is adopted also by Mr. Berry.[2] The latter author has recently instituted a new genus, *Knowltonella*,[3] for some fronds from the Potomac Group of Maryland, characterized by a 'pseudo-dichotomous' habit, a strong rachis, and linear-lanceolate pinnules, which he assigns to the Matoniaceæ; but, in the absence of satisfactory fertile specimens, there would seem to be no adequate reason for this reference. The portions of fronds on which the genus *Knowltonella* is founded bear a close resemblance to *Phlebomeris spectanda* Sap. from the Albian of Portugal.[4]

The specimens of *Matonidium gœpperti* in the Dawson Collection show more clearly than any English examples so far described the habit of the frond and the arrangement of the comparatively large contiguous sori on the under surface of the pinnules. One of the few spores obtained is reproduced in text-fig. 2 C (p. 91); it is triangular in shape, with broadly rounded corners, and is approximately ·06 mm. in diameter; the wall is thick and smooth, and is often more or less depressed along the sides. In the example figured the wall has separated along the three-rayed ridge, leaving a central space. The spores agree closely with some obtained from a pinna of *Matonidium* from the Middle Jurassic beds of the Yorkshire coast, for which I am indebted to Mr. Hamshaw Thomas, and are of the same type as those figured by Schenk[5] from the Wealden of Germany.

Dipteridineæ.

HAUSMANNIA PELLETIERI, sp. nov. (Pl. XIV, figs. 1-3.)

(Fairlight, Dawson Coll.)

The genus *Hausmannia*, founded by Dunker[6] on leaves from the Wealden Beds of North Germany, has not hitherto been recognized with certainty in the Wealden flora of England. It is owing to the zeal and skill of Fathers Pelletier & Teilhard de Chardin that I am now able to describe some particularly good specimens of

[1] Ward (99) p. 653. [2] Berry (11[2]) *passim*.
[3] Berry (11[2]) p. 233 & pls. xxv–xxvii.
[4] Saporta (94) p. 168 & pl. xxx, fig. 1; Zeiller (08) p. 192, fig. 7.
[5] Schenk (76) pl. xxvii, figs. 9 *b* & 9 *c*.
[6] Dunker (46) p. 12.

this interesting fern. The frequent association of *Hausmannia* and *Matonidium* in the Fairlight Clay (Pl. XIV, fig. 3 *a*) bears striking testimony to the fact, that the association on Mount Ophir in the Malay Peninsula of the genera *Dipteris* and *Matonia* is a survival at the present day in the Southern Hemisphere of a sample of European Wealden and Jurassic vegetation. There can be little doubt as to the very close affinity of these two geographically-restricted existing genera to the fossil species of *Hausmannia* and *Matonidium*.

The fronds of *Hausmannia pelletieri* vary in size from the deeply-bilobed form, 2 cm. broad, represented in Pl. XIV, fig. 2 (thrice the natural size), to the larger and more dissected type reproduced (natural size) in fig. 3 of the same plate.

The lamina of the smaller leaf bears a close superficial resemblance to a small form of *Ginkgo biloba* L. or *G. digitata* (Brongn.): in the larger fronds (as, for example, fig. 3) the lamina is divided into obcuneate segments, characterized by a few strong ribs and a reticulum of finer veins. The forked main ribs spread from the summit of a fairly long petiole (fig. 2); from them numerous branches are given off at right angles, and the finer veins form an irregular reticulum with the ultimate branches ending blindly in the polygonal areas.

The species *Hausmannia kohlmanni*, founded by the late Dr. Richter[1] on material from the Lower Cretaceous strata of Strohberg, in Germany, differs from *H. pelletieri* in the less deeply-cut lamina and in the more entire margin. The smaller German species, *H. sewardi* Richt.[2] is distinguished by its entire and obovate lamina. The frond shown in Pl. XIV, fig. 3 closely resembles some forms of *H. dichotoma*[3]; but in that species the segments are usually narrower than in *H. pelletieri*, and the leaves reach larger dimensions.

Comparison may also be made with Bartholin's Lower Jurassic species *H. forchhammeri*,[4] and with *H. crenata* Nath., as figured by Möller[5]: both from Bornholm. The fragments described by Schenk from the German Wealden as *Dictyophyllum rœmeri*[6] are, in all probability, correctly referred to that genus rather than to *Hausmannia*: on the other hand, Heer's *Dictyophyllum dicksoni*[7] from the Kome Beds of Greenland may be a piece of a *Hausmannia* frond. It is also probable that some of the fragments described in Part I of the British 'Wealden Flora' as *Dictyophyllum rœmeri* should be removed to *Hausmannia*; and the same statement applies to a specimen figured from the Wealden of Bernissart as *Protorhipis rœmeri*.[8]

[1] Richter (06) p. 21 & pls. i, ii, v.
[2] *Ibid.* p. 22 & pl. i, fig. 12; pl. v, figs. 3–4.
[3] Seward (11) p. 657 & pl. i, figs. 14–17, 19; pl. ii, fig. 20.
[4] Bartholin (92) pl. xi.
[5] Möller (02) pl. v, figs. 5 & 6.
[6] Schenk (71) pl. xxxi, fig. 3 & pl. xxxvi, figs. 7 *a*–7 *b*.
[7] Heer (74) pl. iii, fig. 9.
[8] Seward (00) p. 18 & pl. iii, fig. 34.

Schizæaceæ.

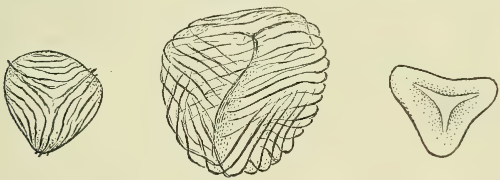
RUFFORDIA GŒPPERTI (Dunk.). (Text-fig. 2 A, below.)

(Fairlight, Dawson Coll.)

1846. *Sphenopteris gœpperti* Dunker, 'Monographie der Norddeutschen Wealdenbildung' p. 4 & pl. i, fig. 6 ; pl. ix, figs. 1–3.
1894. *Ruffordia gœpperti* Seward, 'Wealden Flora' pt. 1, p. 76.

The Dawson Collection includes a piece of fertile frond of the same type as one previously figured from the Hastings district,[1] and from this a few spores were obtained by treatment with Schulze's solution. The spores are ·05 mm. in diameter, and have a rounded triangular form, the surface being characterized by the presence of numerous ridges (text-fig. 2 A) : they agree in shape

Fig. 2.—*Spores of (A)* Ruffordia gœpperti ; *(B)* Pelletieria valdensis; *and (C)* Matonidium gœpperti *(all considerably enlarged).*



and sculpturing with those of certain recent Schizæaceous ferns, and are similar to the spores of Mr. Berry's Potomac fern *Schizæopsis americana*.[2] In his earlier paper in the 'Annals of Botany' the fern which he afterwards named *Schizæopsis americana* was regarded as specifically identical with *Baieropsis expansa* Font., and referred to as *Schizæopsis expansa*. The spores of the recent species *Aneimia tomentosa* Sw. and *Mohria caffrorum* Desv., which are of the same type as those of *Ruffordia*, measure respectively 0·1 mm. and 0·8 mm. in breadth.

No sporangia have been found ; but the structure of these spores supports the inference, based on the habit of the fertile and sterile fronds, as to a Schizæaceous alliance.

PELLETIERIA VALDENSIS, gen. et sp. nov. (Pl. XII, figs. 12 *a* & 12 *b* ; Pl. XIV, fig. 5. Also text-figs. 2 B, 3, & 4.)

(Fairlight Clay, Dawson Coll. ; near Hastings, Rufford Coll.)

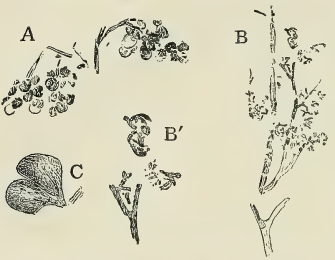
The specimens on which this new genus is founded do not afford sufficient data on which to base a complete diagnosis, nor do they

[1] Seward (94) pl. v, fig. 5.
[2] Berry (11) pl. xii ; *id.* (11²) pl. xxii, figs. 4–9.

supply such evidence as is needed to establish definitely the affinity of the plant. The specimens which first attracted my attention are those represented in Pl. XII, fig. 12 *a* and in text-fig. 4 (p. 93), and a search through the Rufford Collection led to the discovery of the larger specimens of the same type reproduced in text-fig. 3, below. As all the examples are clearly of the same type, a single diagnosis may serve for genus and species.

Fertile fronds, with little or no sterile lamina, consisting of a slender main axis giving off lateral branches at an acute angle which bifurcate repeatedly, the ultimate ramifications being very thin and divergent (text-fig. 3 B). At the tips of the fertile branches are borne more or less spherical carbonized bodies, approximately 2 mm. long, enclosing a very large number of tetrahedral spores 60 to 70 μ in diameter, and characterized by well-defined surface-ridges (Pl. XIV, fig. 5 & text-fig. 2 B), and a form of sculpturing met with in recent species of Schizæaceæ and in the tropical water-fern *Ceratopteris*.

Fig. 3.—Pelletieria valdensis: A, B, B′ =*pieces of fertile fronds; C=two spore-masses.*



[A & B are of the natural size; B′ is magnified by 2 diameters, and C by 9.]

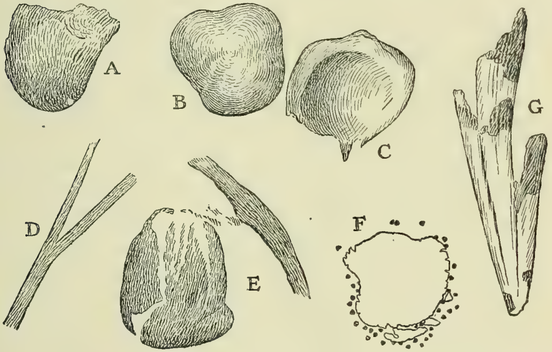
There is no conclusive evidence in regard to the nature of the sterile pinnules, but the juxtaposition of some narrow cuneate segments [1] (text-fig. 4 G, p. 93) may be an indication of their form. No sporangia have been recognized.

The imperfect and broken specimen represented of the natural size in text-fig. 3 B, affords the best example of the habit of the fertile frond; at the apices of a few of the branchlets are portions of the spore-masses. A piece of the upper part of the specimen is shown twice the natural size in fig. 3 B′. The occurrence of the fertile segments or spore-masses in connexion with the slender branches is shown more clearly in Pl. XII, fig. 12 *a*, and in text-fig. 3 A. One of the spore-masses with its carbonized covering is enlarged in fig. 12 *b*; and in text-fig. 4 (p. 93) an attempt is made to show the forms assumed by these bodies, many of which are scattered through the shale. They are often strongly convex (text-fig. 3 C), and in a few examples, as, for instance, the upper of the two shown in fig. 3 C, there appears to be a continuation of the short stalk as a median line or rib over the convex back of the spore-enclosing body. In

[1] Compare the segments of *Sphenopteris fontainei* Seward (94) pl. vii, fig. 2.

some specimens (for instance, A & E, text-fig. 4) the carbonized covering is broken at the distal end: there is, however, no decisive evidence as to the nature of this structure, whether it is a capsule or an inrolled fertile piece of lamina. The spore-masses, on separation from the covering and on treatment with macerating solution, show no indication of grouping into sporangial masses within the whole group. Two of the spores are reproduced in Pl. XIV, fig. 5, and text-fig. 2 B (p. 91). Text-fig. 4 F, below, represents in outline part of a carbonized covering, in which no cell-outlines are visible, with some of the spores beyond its ragged edge. Text-fig. 4 D

Fig. 4.—Pelletieria valdensis: A–C, E, & F=*spore-masses with covering;* D=*piece of axis;* G=*pinnule.* *(Magnified by 9 diameters.)*



is probably a piece of a forked axis. The surface-sculpturing of the spores is of the same type as in several Schizæaceous ferns: the spores of *Mohria caffrorum* Desv. have a diameter of 80 μ and those of *Aneimia tomentosa* Sw. a diameter of 110 μ, as compared with 60 to 70 μ in *Pelletieria.* Mr. Boodle [1] discovered numerous petrified spores in the tissues of the Wealden fern *Tempskya,* 65 μ in diameter, which bear a very close resemblance to those of *Pelletieria.*

The spores of *Schizæopsis,* a genus already mentioned, which was recently instituted by Mr. Berry for certain Potomac fossils originally described by Fontaine as species of his genus *Baieropsis,* are very similar to that shown in Pl. XIV, fig. 5: they have a diameter of 100 μ. Mr. Berry [2] regards the spore-masses of his fern—spindle-shaped bodies 4 mm. long and 1 mm. broad—as consisting of a

[1] Boodle (95). [2] Berry (11) p. 195.

large number of closely-packed sporangia; but, just as in the Sussex specimens, there is no evidence as to the nature of the sporangia.

A specimen figured by Fontaine as *Baieropsis pluripartita* [1] bears small oval bodies, regarded by the American author as seeds, which bear a fairly close resemblance to the spore-masses of *Pelletieria.* Fontaine's species is included by Berry [2] in the genus *Acrostichopteris.*

A fragment figured by Saporta from the Lower Cretaceous beds of Portugal as *Pteridoleima spoliatum* [3] is not unlike the fossil represented in text-fig. 3 B (p. 92). Fertile specimens of the Cretaceous species *Onoclea inquirenda* Holl.[4] may be compared with the English specimen, but the habit is distinct.

Dr. Stopes & Dr. Fujii [5] have described a specimen from the Upper Cretaceous rocks of Northern Japan under the name of *Schizæopteris mesozoica*, which in the occurrence of sporangia in groups suggests comparison with the Wealden species. In the Japanese type the sporangia are preserved; whereas in *Pelletieria* there is no indication of individual sporangia within the enclosing membrane.

The habit of *Pelletieria* reminds one of the fertile pinnæ of *Thyrsopteris elegans*, with the cup-shaped indusia and protruding groups of sporangia like miniature bunches of grapes; but in *Thyrsopteris* the spores are smooth, and in *Pelletieria* there is no indication of any cup-shaped indusium. The fertile portions of some *Botrychium* fronds present a certain resemblance to those of the Wealden fern, but the spores have no surface-ridges.

Some of the fertile pinnæ of Jurassic ferns from Cracow, figured by Raciborski [6] as species of *Dicksonia* (more fittingly named *Coniopteris*), are of the *Thyrsopteris* type and similar to the English fossils.

The structure of the spores of *Pelletieria* is a feature in favour of assigning the genus provisionally to the Schizæaceæ. The habit of *Ceratopteris* fronds, the spores of which are of the same ribbed type as, though larger (130 μ in diameter) than, those of *Pelletieria*, differs much more widely from that of the Wealden species than is the case with Schizæaceous species.

The degree of importance to be attached to the size and surface-ornamentation of fern-spores as taxonomic criteria has not been satisfactorily defined; and, in view of the comparatively large number of fossil fern-spores now described by palæobotanical authors, it is proposed to make a critical examination of the spores of recent species.

[1] Fontaine (89) pl. xc, figs. 4 & 4 *a*.
[2] Berry (10) p. 631.
[3] Saporta (94) pl. xvi, fig. 25.
[4] Berry (11^3) pl. xviii, figs. 1 & 1 *a*.
[5] Stopes & Fujii (10) p. 6.
[6] Raciborski (94) pl. xii, figs. 8, 11, etc.

Schizæaceæ (?).

CLADOPHLEBIS BROWNIANA (Dunk.). (Pl. XIII.)

(Fairlight, Dawson Coll.)

1846. *Pecopteris browniana* Dunker, 'Monographie der Norddeutschen Wealdenbildung' p. 5 & pl. viii, fig. 7.
——. *P. ungeri* Dunker, *ibid.* p. 6 & pl. ix, fig. 10.
1869. *P. dunkeri* Schimper, 'Traité de Paléontologie Végétale' vol. i, p. 539.

It has been pointed out by Lester Ward [1] that, as the specimens figured by Dunker as *Pecopteris ungeri* are generally considered to be indistinguishable from those assigned to *Cladophlebis dunkeri*, the older name should be retained: Mr. Berry, in his recent monograph, also conforms to the strict rule of priority. In the description of the Wealden plants in the British Museum (Natural History) attention was drawn to the difficulty of separating certain specimens referred by authors to *Cl. browniana* and *Cl. dunkeri*, but both names were retained. A further examination of the English material led me to adopt the name *Cl. browniana* [2] in a wider sense, as including examples previously assigned to *Cl. dunkeri*. Mr. Berry, while agreeing with me as to the close similarity between *Cl. browniana* and *Cl. dunkeri*, prefers to retain both specific names, *Cl. ungeri* being substituted for *Cl. dunkeri*.[3]

The photographs reproduced in Pl. XIII show portions of an exceptionally large and instructive specimen in the Dawson Collection. Fig. 1 shows a rachis, or pinna-axis, bearing alternate linear-lanceolate pinnæ with straight or slightly-falcate linear pinnules, most of which have a crenulate margin, while others are entire. This piece of frond is interesting, because of the evidence it supplies of a transition between the two forms of segments, supporting the view that the fern described by Dunker as *Pecopteris browniana* is not specifically distinct from *Cl. dunkeri* (Schimp.). The larger piece shown in fig. 2 bears short pinnate branches in which the crenulate pinnules of fig. 1 are replaced by short and entire ultimate segments. The close association of the two specimens (figs. 1 & 2), each of which is only reproduced in part, on one piece of rock renders it almost certain that they belong to one large frond.

The following references afford further illustration of the difficulty—or, indeed, impossibility—of separating *Cladophlebis browniana* and *Cl. dunkeri*:—

Fontaine in Ward (05) pl. lxv, figs. 9–11 (*Cl. browniana*), figs. 15 & 16 (*Cl. ungeri*): Nathorst's and Yokoyama's Japanese specimens, Nathorst (90) pl. iv, figs. 2, 6, pl. v, fig. 5, & pl. vi, fig. 4; Yokoyama (94) pl. xiv, figs. 2 & 3: also Saporta (94) pl. xii, figs. 2 & 3 (*Pecopteris browniana*). The fern figured by Dr. Yabe from Jurassic beds in Korea as *Cl. koraiensis*, may be an example of *Cl. browniana* [Yabe (05) pl. ii, fig. 1 & pl. iii, figs. 12–13].

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[1] Ward (05) p. 228, footnote 1.
[2] Seward (08) p. 11.
[3] Berry (11^2) p. 257.

It is, however, hardly possible, at least in some cases, to distinguish between the species *Cladophlebis browniana* and *Klukia exilis* (Phill.).

Prof. Zeiller[1] has recently recorded the occurrence of fertile pinnæ of a fern from the Wealden of Peru, which he regards as closely allied to *Pecopteris browniana*; and a fern from the same country figured by Dr. Salfeld[2] as *Cladophlebis* sp., cf. *Coniopteris arguta* Lind. & Hutt., appears to be identical with *Cl. browniana.* The same remark is applicable to this author's *Filicites (?Alethopteris) ellensis.*

It is interesting, in view of the close agreement between *Klukia exilis*[3] and *Cl. browniana*, to find that Prof. Zeiller speaks of the fertile pinnæ of his Peruvian fern as possessing ovoid sporangia of the Schizæaceous type.

Polypodiaceæ.

ONYCHIOPSIS MANTELLI (Brongn.).

(Fairlight, Dawson Coll.)

1824. *Hymenopteris psilotoides* Stokes & Webb, Trans. Geol. Soc. ser. 2, vol. i, pt. 2, p. 424 & pl. xlvi, fig. 7.

1828. *Sphenopteris mantelli* Brongniart, 'Histoire des Végétaux Fossiles' p. 170 & pl. xlv, figs. 3–7.

This species is represented by a clearly-defined impression, in which the ultimate segments are a little larger than in most of the previously recorded examples, but slightly smaller than the pinnules of specimens referred to *Onychiopsis elongata* (Geyl.) in Part I of the 'Wealden Flora.'

The American authors Ward[4] and Berry[5] have adopted for this species the name *Onychiopsis psilotoides* (Stokes & Webb); but, in view of the long usage of the designation *mantelli* and the fragmentary nature of the fossil figured by Stokes & Webb, I retain the more familiar name. A re-examination of the English material led me to regard the forms previously assigned to the two species *O. mantelli* and *O. elongata* as one species. Mr. Berry has, however, examined some of the Japanese fossils described by Dr. Yokoyama as *O. elongata*, and his view is that they are not specifically identical with the Potomac plant referred to *O. psilotoides.* This author includes *O. elongata* in his synonymy of *O. gœpperti* (Schenk).

EUFILICINEÆ INCERTÆ SEDIS.

TEILHARDIA VALDENSIS, gen. et sp. nov. (Pl. XI, figs. 7 *a*–9 *b*.)

(Fairlight Clay, Ecclesbourne, near Hastings; Rufford Coll.)

The fertile impressions represented in Pl. XI, figs. 7 *a*–9 *b*, occur

[1] Zeiller (10).

[2] Salfeld (09) p. 214 & pl. iii, fig. 4.

[3] For figures of *Klukia*, see Raciborski (94) pl. viii, figs. 1–3, 7–9 *b*; also Seward (12) pl. vi, fig. 81 & pl. vii, fig. 88.

[4] Ward (05) p. 155.

[5] Berry (11^2) p. 274.

together in some small pieces of ironstone from Ecclesbourne, and there is no doubt as to their specific identity; the form of pinnule shown in Pl. XI, fig. 9 *a*, is connected by transitional stages with that reproduced in figs. 7 *a* & 8 *a*, and the sori in both kinds of pinnules are the same. No sporangia or spores have been found. The longer and narrower type of fertile pinnule (fig. 7 *b*) reminds one of those of *Cladophlebis browniana* and *Klukia exilis*; but the size of the elliptical patches on each side of the midrib suggests sori rather than the single sporangia of *Klukia*. Moreover, the pinnules are more erect in the Wealden specimens, and the segments seen in Pl. XI, fig. 9 *b* are distinct from any observed in *Cl. browniana* and *Klukia exilis*.

Although the data are inadequate for accurate determination of affinity, I venture to institute a new generic name, after Father Teilhard de Chardin, for this Wealden fern, which differs in certain respects from any known type.

Frond tripinnate; pinnæ linear, alternate; pinnules on the smaller branches more or less deltoid, with obtuse apices; other pinnules linear and relatively narrower, entire, or crenulate (fig. 8 *b*), and attached almost at right angles to the pinna-axis. Venation very imperfectly preserved: as already stated, no sporangia or spores have been discovered.

FILIX *incertæ sedis*. (Pl. XI, fig. 10.)

(Near Hastings, Rufford Coll.)

The specimen shown in fig. 10 is described in Part I of the 'Wealden Flora'[1] as probably a fragment of *Sagenopteris mantelli* accidentally associated with a rachis-like axis. A more careful examination leads me to regard the leaflets as pinnules of a fern, in association with a piece of rachis to which the lower leaflet is attached. There is a clearly-marked midrib, as also numerous secondary veins which are obscurely preserved: the lamina is contracted at the base, and agrees in shape with that of *Neuropteris* pinnules.

Comparison may be made with a specimen figured by Schenk from the Wealden of Germany as *Alethopteris huttoni*,[2] and with *Cladophlebis constricta* Font.[3]

It is possible that these pinnules were borne as *Aphlebia*-leaflets on the petiole of a fern which possessed pinnæ with smaller pinnules; but there is nothing to support this suggestion, except the analogy of some Palæozoic fronds.

1 Seward (94) p. 134.

2 Schenk (71) pl. xxix, fig. 1. [Since the above description was written, it has been pointed out by Herr Huth that *Neuropteris huttoni* Dunk. (=*Alethopteris huttoni*) is a fragment of the Carboniferous species *Mariopteris muricata*: see Zobel (12) p. 262. Herr Zobel has identified the specimen figured by Schenk as *Marsilidium speciosum*, and included by him as a Wealden type, as *Sphenophyllum thoni* Mahr.]

3 Berry (11^2) p. 246 & pl. xxix, fig. 3.

APHLEBIA sp. (Pl. XIV, fig. 4.)

(Fairlight Clay, Ecclesbourne; Rufford Coll.)

The irregularly dissected leaf-like organ shown in fig. 4 (4 cm. × 3·3 cm.) has no well-defined veins; but the surface is characterized by numerous spreading striations or wrinklings, which may be the result of contraction.

A specimen described as *Aphlebia* from the Upper Jurassic beds of Sutherland[1] has been compared with the stipules of recent Marattiaceous ferns, and it is not unlikely that the Wealden fossil is of this nature. In size, as also in the uneven margin, the specimen agrees closely with the stipules of *Marattia fraxinea*.[2]

Some ovate entire leaves with forked and spreading veins, recently described by Dr. Halle[3] from the Middle Jurassic beds of Yorkshire under a new generic designation, *Cloughtonia*, may be closely allied to the Wealden fossil. Halle is inclined to regard *Cloughtonia* as bracteal, and possibly borne on some highly-developed Gymnosperm; he also suggests comparison with large Angiospermous petals.

One cannot speak with any confidence as to the nature of these detached scales, but I am inclined to think that the comparison with stipular or aphleboid organs is the more appropriate.

Some Wealden specimens from South Africa, described as *Cycadolepis jenkinsiana* (Tate),[4] may perhaps be of the same general type as the English example.

Planta incertæ sedis.

(? EUFILICINEÆ.)

DICHOPTERIS DELICATULA, sp. nov. (Pl. XI, figs. 6 *a* & 6 *b*.)

(Fairlight, Dawson Coll.)

The specimen on which this species is founded exhibits the following characters:—Rachis and axes of pinnæ relatively stout and prominent; pinnæ alternate. Pinnules alternate, with a fairly thick lamina, a deltoid or broadly-linear blunt apex, attached by the whole base; no veins shown.

The form of the pinnæ reminds one of species of *Gleichenites*, or of the Sussex specimens previously described under the name *Leckenbya valdensis*,[5] and subsequently referred to *Gleichenites cycadina* (Schenk)[6]; but *Dichopteris delicatula* is distinguished by the form of the pinnules, which show no sign of a lobed base, and by the absence of the *Cladophlebis* type of venation. Superficially, there is a fairly close similarity to some of the Sussex fossils described as *Sphenopteris fittoni* Sew.[7]; but in that species the pinnæ are shorter, the pinnules more acute and often lobed.

[1] Seward (11) p. 674, text-fig. 6.
[2] Seward (10) p. 317, fig. 41 B.
[3] Halle (11).
[4] Seward (03) pl. iv, figs. 3 & 4.
[5] Seward (95) p. 225.
[6] Seward (11) p. 664.
[7] Seward (94) p. 107, pl. vi, fig. 2 & pl. vii, fig. 1.

The fronds figured by Saporta from the Kimmeridgian of Orbagnoux (Ain), and from Portugal, as *Scleropteris zeilleri* [1] agree very closely with the English type; and an equally close resemblance is presented by *S. pomeli* Sap.,[2] a type recently recorded from Sutherland under the generic name *Dichopteris*, which was adopted in preference to Saporta's generic term *Scleropteris*.[3]

CYCADOPHYTA.

Bennettitales.

Williamsonia carruthersi (?) Sew.

(Fairlight, Rufford Coll.)

1895. A. C. Seward, 'Wealden Flora' pt. 2, p. 157 & pls. x–xi.

A specimen in the Rufford Collection (V 3766), acquired by the British Museum (Natural History) since the publication of the 'Wealden Flora,' is worthy of notice as being probably a peduncle of *W. carruthersi*. It is the impression of an axis 13 cm. long, which, with the exception of some crowded leaf-scars at one end, is characterized by the occurrence of narrow and rather widely-separated scars, probably marking the position of linear bracts. These scars are 2 to 2·5 cm. apart in a vertical line; they agree in size and shape with the bracts of the fructification of *W. carruthersi*.[4] The specimen may be compared with peduncles of *Williamsonia* from the Jurassic rocks of Yorkshire.[5] If the assumption that this Wealden peduncle bore an apical flower of *W. carruthersi* is correct, it affords an argument in support of the adoption of the generic name *Williamsonia* in preference to *Bennettites*.

CYCADOPHYTA INCERTÆ SEDIS.

Otozamites klipsteinii (Dunk.). (Text-fig. 5, p. 100.)

(Fairlight Clay, near Cliff End, Hastings; Rufford Coll.)

1846. *Cyclopteris klipsteini*, Dunker, 'Monographie der Norddeutschen Wealdenbildung' p. 11 & pl. ix, figs. 6–7.

1895. *Otozamites klipsteinii* Seward, 'Wealden Flora' pt. 2, p. 60 & pl. i, figs. 3–4; pl. vii.

In the 'Wealden Flora' some specimens were referred to Dunker's species, although the size of the pinnæ greatly exceeds that of the type-specimen and the examples subsequently figured by Schenk.[6] The specimen reproduced in text-fig. 5 (V 3709) affords

[1] Saporta (91) p. 434 & pl. cclxxxviii (or lxii), fig. 1; *id.* (94) p. 46, pl. x, fig. 2; pl. xi, figs. 14–15; & pl. xii, fig. 1.
[2] Saporta (73) pl. xlvi, fig. 1 & pl. xlvii, figs. 1–2.
[3] Seward (11) p. 678, pl. iii, fig. 55 & pl. iv, fig. 71; see also Seward (10) p. 552.
[4] *Cf.* Seward (95) pl. x, fig. 1 & pl. xv, fig. 3.
[5] Saporta (91) pls. xv–xvii; Seward (97); Wieland (11).
[6] Schenk (71) pl. xxxi, fig. 6.

Fig. 5.—Otozamites klipsteinii (*Dunk.*). *(Natural size.)*

confirmation of the extension of Dunker's definition of the species, to include pinnæ considerably larger than any obtained by him from German strata.

Specimens of *Otozamites* similar to *O. klipsteinii* have recently been figured by Mr. Hamshaw Thomas [1] from Jurassic beds in Southern Russia.

CTENIS sp. (Pl. XII, figs. 1 *a*, 1 *b*, & 2.) (Rufford Coll.)

The pieces of linear pinnæ represented in figs. 1 & 2, although too small to be assigned to a species, afford evidence of the occurrence of the genus *Ctenis* in the Wealden flora. The enlarged drawing (fig. 1 *b*) shows very clearly the *Ctenis* type of venation.

A frond previously figured from the Sussex coast as *(?) Zamites* sp.[2] was compared with *Ctenis*, which it closely resembles in habit; but no anastomosing veins were discovered. In all probability, that specimen is specifically identical with fronds from the Kimmeridgian beds of Sutherland, for which a new generic name, *Pseudoctenis*,[3] has been instituted.

CYCADEAN STEMS.

The Dawson Collection includes a few pieces of Cycadean stems, which agree generally, in the form of the leaf-bases or persistent scale-leaves, with *Bucklandia anomala* Carr.[4] One of them has rhomboidal leaf-bases, 2 cm. deep by 2·2 cm. in breadth, which are very similar to those on Jurassic stems assigned to *Williamsonia gigas*.[5] Another specimen represents a narrow and incomplete stem 39 cm. long, with a few imperfect leaf-bases like those of *Bucklandia*, *Yatesia*, and *Fittonia*, genera which are not distinguishable by well-defined characters. This and other examples of stems from the Sussex coast show that some of the Cycadean plants of the Wealden flora possessed long and narrow stems like those of some recent species of *Cycas* and the genus *Microcycas*; and the absence of any fertile lateral shoots of the Bennettitean type is an interesting feature, pointing to the occurrence of flowers either at the apex of the main stem, or on elongated peduncles of the *Williamsonia* type.

EURY-CYCADOLEPIS. (Pl. XII, figs. 3 *a*–4 *c*; Pl. XIV, fig. 6; and text-fig. 6, p. 102.)

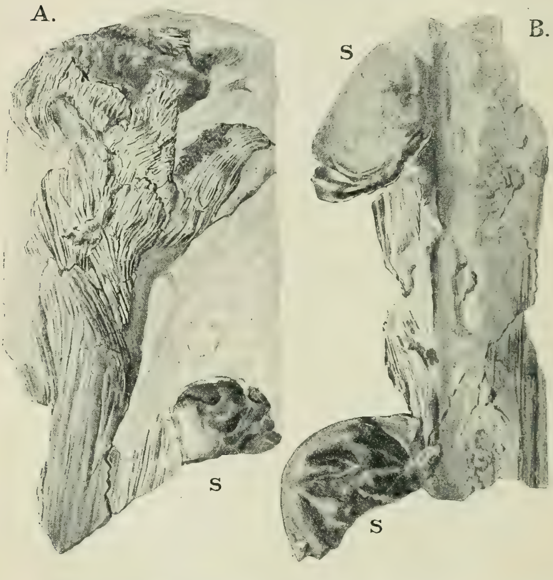
(Fairlight Clay, Fairlight; Dawson Coll.)

In Part II of the 'Wealden Flora' several specimens were described under Saporta's generic term *Cycadolepis*, the broader

[1] Thomas (11) pl. v, fig. 11 & pl. vi, figs. 1–2. [2] Seward (95) p. 89, fig. 5.
[3] Seward (11) p. 692. [4] Carruthers (70) pl. liv, figs. 1–3.
[5] Williamson (70) pl. liii, fig. 5. A similar stem has been recorded from the Uitenhage Series (Wealden) of Cape Colony: Seward (07) pl. xxi, fig. 9.

and larger examples being referred to a sub-genus *Eury-Cycadolepis*.[1] None were found in connexion with stems. Additional examples of these scales were figured in an account of the Uitenhage Flora of Cape Colony.[2] The Dawson Collection includes several specimens of *Eury-Cycadolepis*, which supply some fresh information as to these curious organs.

Fig. 6.—Eury-Cycadolepis *sp.* *A & B = Casts of stems with scales* (S). *(Half of the natural size.)*



The following descriptions are given, in the hope that further search may lead to the discovery of specimens which will afford more decisive evidence as to the morphology of the scales :—

Pl. XII, fig. 3 *a*. This small scale, superficially recalling the test of a *Terebratula*, is covered at the narrow end with a fairly thick layer of coal which on magnification (fig. 3*b*) shows numerous striations roughly parallel to its long axis. Below the coal (fig. 3*c*) is a reticulate pattern on which are superposed longitudinal striations similar to those on the carbonized surface.

[1] Seward (95) p. 96. [2] Seward (03) pp. 31–32.

Pl. XII, fig. 4*a*. The scale, shown half of the natural size in fig. 4*a*, measures 10×6 cm.; it is slightly convex, and rather sharply bent down at the left-hand edge, while at the upper margin it is in organic connexion with a piece of woody axis. The dark band encircling an area near the centre is due to the presence of carbonaceous matter, and has no significance. Over the whole surface is a raised reticulum with meshes varying in size and shape (Pl. XII, figs. 4*b* & 4*c*): towards the right-hand edge this reticulum passes into irregularly anastomosing ridges (fig. 4*c*). This surface-sculpturing may be due to the shrinkage of a thick scale originally covered by a felt of hairs, as are the scales of *Dioon* and some other Cycads.

Text-fig. 6 A (p. 102). This specimen (half of the natural size) consists of a sandstone cast of a portion of a stem with imperfectly preserved attached scales, one of which is shown at S. The irregular sinuous lines in the upper part of the stem indicate the presence of other scales lying on the stem.

Text-fig. 6 B (p. 102). In this example there is similar evidence of the attachment of scales (S, S) to a stem; and the occurrence of ridges and striations oblique to the stem suggests the former presence of a complete covering of scales.

Pl. XIV, fig. 6. An imperfectly-preserved carbonized scale, like those shown in text-fig, 6 B and in Pl. XII, fig. 4*a*, when treated with Schulze's solution, yielded pieces of cuticle showing numerous stomata and the outlines of very thick-walled epidermal cells. The stomata agree in the form of the guard-cells with those of recent Cycads.

The additional information supplied by these specimens, although not sufficient to settle definitely the systematic position of the fossils, gives some support to the opinions expressed in Part II of the 'Wealden Flora.'

Planta incertæ sedis.

Conites berryi, sp. nov. (Pl. XII, fig. 13.) (Rufford Coll.)

1895. *Conites armatus* Seward, 'Wealden Flora' pt. 2, p. 222 & pl. ix. fig. 7.

When the specific name *armatus* was given to this Wealden cone in 1895, the previous use of the designation *Conites armatus* by Sternberg[1] was unfortunately overlooked. The obscure fossil so named by Sternberg was subsequently transferred to *Equisetites priscus* Gein. by Feistmantel,[2] in his account of the Radnitz flora. The new specific title is chosen in recognition of the valuable contributions to our knowledge of Potomac plants made by Mr. E. W. Berry.

The portion of a cone shown in fig. 13 is less incomplete than the type-specimen: the cone-scales are oval or more or less polygonal, with a strong angular spine similar to that observed on the

[1] Sternberg (25) p. xxxix & pl. xlvi, fig. 1.
[2] Feistmantel (75) p. 94.

scales of *Pinus coulteri* Don and other recent species. There is, however, no evidence as to the nature of the seeds; and the taxonomic position of the species, whether a Conifer or a Cycad, is still in doubt. The close resemblance in the form of the scales to those of *Androstrobus nathorsti* Sew.[1] is worthy of remark, although the habit of that species is a distinguishing feature.

CONIFERALES.

Araucarineæ.

Araucarites pippingfordensis (Ung.).

(Fairlight Clay, Fairlight; Dawson Coll.)

1836. 'A Cone of an unknown Species ...... from Pippingford in Ashdown Forest': Fitton, Trans. Geol. Soc. ser. 2, vol. iv, pt. 2, p. 181 & pl. xxii, fig. 10.
1850. *Zamiostrobus pippingfordensis* Unger, 'Gen. Spec. Plant. Foss.' p. 300.

A comparison of the well-preserved impression in the Dawson Collection with Unger's type-specimen in the British Museum (Natural History) leads me to adopt his specific name. Mr. Carruthers[2] substituted the genus *Araucarites* for *Zamiostrobus*, in view of the very close resemblance of Unger's species to the Jurassic *A. sphærocarpus* Carr. and similar cones.

This recently-acquired specimen is an impression of an almost spherical cone (6 × 5 cm.) consisting of woody scales with rhomboidal distal ends, 9 mm. broad and 5 to 6 mm. deep, with a transverse ridge extending over the exposed surface immediately above a median oval scar or umbo. The Wealden cone previously described as *A.* (*Conites*) sp. is no doubt a very closely-allied, if not an identical, type.[3]

Araucarites sp. (Pl. XII, fig. 5.) (Dawson Coll.)

The cone-scale shown in Pl. XII, fig. 5, may belong to *A. pippingfordensis.* The form of the scale, which bears a single seed, is very similar to that of other Araucarian cone-scales described from American localities[4]; but it is futile to attempt an accurate specific identification of imperfectly-preserved specimens of this kind. The specimen is figured, in illustration of the occurrence of an Araucarian scale rather larger than any hitherto recorded from British Wealden localities.

Abietineæ.

Pinites solmsi Sew. (Rufford Coll.)

1895. A. C. Seward, 'Wealden Flora' pt. 2, p. 196 & pl. xviii, figs. 2–3; pl. xix.

A specimen in the Rufford Collection (V 3695) is worthy of

[1] Seward (95) pl. ix, fig. 1. [2] Carruthers (69) p. 3.
[3] Seward (95) p. 191 & pl. xii, figs. 1–2.
[4] Ward (99) pl. clxiii; Berry (11^2) p. 399 & pl. lxxvii, fig. 5.

mention, as illustrating more clearly than any examples hitherto described the alternation on a slender shoot of small crowded leaf-scars with more widely separated scars. This type of branch is fairly common, both in Wealden and in Jurassic floras; and, in some cases at least, there can be no doubt as to the close affinity of such shoots to those of recent Abietineæ.

PINITES sp., cf. P. DUNKERI Carr. (Pl. XII, figs. 6 & 7.)
(Fairlight Clay, Fairlight; Dawson Coll.)

1866. *Pinites dunkeri* Carruthers, Geol. Mag. vol. iii, p. 542.

The imperfect scale shown in Pl. XII, fig. 6 is characterized by a broad and bluntly-rounded distal end, 8 mm. wide, with a terminal umbo. At the lower end is the faint impression of a seed, or probably two small contiguous seeds. In general appearance the specimen bears a close resemblance to the seminiferous scales of the Himalayan pine, *Pinus excelsa* Wall. At the base of the scale represented in Pl. XII, fig. 7 the presence of two seeds is clearly shown.

It is impossible to speak with confidence as to the specific identification of these two scales; but a comparison with the scales of the large Wealden cone *P. dunkeri* Carr. leads me to suggest identity with that species. While it is hopeless to attempt a satisfactory diagnosis of the different forms of Lower Cretaceous cones, it is a significant fact that in the vegetation of this period the Abietineæ play a prominent part. In addition to the species of Abietineous cones mentioned in the 'Wealden Flora,' reference may be made to specimens described by American authors from the Shasta Formation of California and the Potomac Group as *Abietites macrocarpus* Font. and *A. angusticarpus* Font.,[1] which are hardly distinguishable from *Pinites dunkeri*. Comparison may also be made with cones figured by Fliche from Lower Cretaceous beds in the Argonne, as, for example, *P. andræi* Coem.[2] Some of the seed-bearing scales described by Prof. Nathorst as *Pityolepis tolli*[3] from Jurassic beds in Kotelny (New Siberian Islands) are similar to those reproduced in Pl. XII, figs. 6 & 7, but they differ in shape and are larger.

Species Coniferarum incertæ sedis.

SPHENOLEPIDIUM KURRIANUM (Dunk.). (Pl. XII, figs. 10 *a* & 10 *b*.)
(Dawson Coll.)

1846. *Thuites (Cupressites?) kurrianus* Dunker, 'Monographie der Norddeutschen Wealdenbildung' p. 20 & pl. vii, fig. 8.

The small cone shown in fig. 10 *a* occurs in association with slender shoots bearing spirally-disposed leaves, and agrees closely

[1] Fontaine (89) pl. cxxxii; Fontaine in Ward (05) pl. lxviii, figs. 15–16, pl. cxiv, fig. 10, & pl. cxv, figs. 2–3.
[2] Fliche (96) p. 115 & pl. x, figs. 3–4. [3] Nathorst (07) pl. ii, especially fig. 3.

with fertile shoots referred to *Sphenolepidium kurrianum*.[1] Some of the seeds have a median distal process (fig. 10 *b*), a feature not hitherto noticed.

Further information as to the structure of this common type is required before it can be assigned to its position in the Coniferales: the use of such generic names as *Athrotaxopsis*,[2] *Taxodium*, *Glyptostrobus*, and *Widdringtonites* is altogether unjustifiable.

Planta incertæ sedis, α. (Pl. XII, figs. 8 & 9.) (Dawson Coll.)

The incomplete specimens shown in Pl. XII, figs. 8 & 9 are clearly of the same type. That represented in fig. 9 consists of a central region, with the remains of a thin torn membrane on each side characterized by numerous, spreading, vein-like impressions. In the lower part of the median region is a prominent convexity, measuring 7×4 mm., possibly caused by a seed; beyond this the axial region is slightly depressed, and tapers gradually upwards.

A similar seed-like prominence is seen in fig. 8, and the thin membrane appears to be attached along two obliquely-ascending lines, meeting in the apical region.

An obvious comparison is with the cone-scales of *Araucarites*, of the type represented by recent species in the section Eutacta, but this resemblance may well be misleading. It is possible that these two fossils are the basal portions of petioles provided with stipular or winged appendages; but more complete specimens are needed to establish the nature of these problematical organisms.

Planta incertæ sedis, β. (Pl. XII, fig. 11.) (Dawson Coll.)

This specimen consists of an approximately circular funnel-like body, 7 mm. in diameter, partly covered with a thick film of coal. The sides of the depression are longitudinally striated. The reverse (fig. 11) shows the striations radiating from the apex of the conical elevation.

It is impossible to speak with confidence as to the nature of this fossil: it differs in form from Equisetaceous diaphragms, but it is similar to, though smaller than, the impressions described by Williamson[3] as the infundibuliform disc of *Williamsonia* [*Zamia*]. A very obscure specimen from the Potomac Group, described as *W. (?) gallinacea*,[4] may also be compared with the fossil shown in Pl. XII, fig. 11.

III. General Survey of the Wealden Floras.

The following list includes both the British Wealden plants mentioned in the 'Wealden Flora' and subsequent additions:—

[1] For the most recent synonymy, see Berry (11[2]) p. 432.
[2] Fontaine (89) p. 239.
[3] Williamson (70) pl. lii, fig. 2.
[4] Ward (05) pl. cvii, fig. 4.

THALLOPHYTA.

Algites valdensis Sew.
Algites catenelloides Sew.

CHAROPHYTA.

Chara knowltoni Sew.

BRYOPHYTA.

Marchantites zeilleri Sew.

PTERIDOPHYTA.

EQUISETALES.

Equisetites lyelli Mant.
Equisetites burchardti Dunk.
Equisetites yokoyamæ Sew.

LYCOPODIALES.

Lycopodites teilhardi, sp. nov.
Selaginellites dawsoni, sp. nov.
[*Planta incertæ sedis*, Seward (94) p. 20 & pl. i, figs. 8–9.]

FILICALES.

? Hydropterideæ.

Sagenopteris mantelli (Dunk.).
Sagenopteris acutifolia Sew.

Eufilicineæ.

Matonineæ.

Matonidium gœpperti (Ett.).
Laccopteris dunkeri Schenk.

Dipteridineæ.

Hausmannia pelletieri, sp. nov.

Gleicheniaceæ.

Gleichenites cycadina (Schenk) [= *Nathorstia valdensis* & *Leckenbya valdensis*, Seward (94) p. 145 & (95) p. 225.]

Cyatheaceæ.

Protopteris witteana Schenk.

Schizæaceæ.

Ruffordia gœpperti (Dunk.).

? Schizæaceæ.

Cladophlebis browniana (Dunk.).
Tempskya schimperi Corda.
Pelletieria valdensis, gen. et sp. nov.

Polypodiaceæ.

Onychiopsis mantelli (Brongn.) [including *O. elongata* (Geyl.) Seward (94) p. 55].

Eufilicineæ incertæ sedis.

Cladophlebis albertsii (Dunk.).
Cladophlebis longipennis Sew.
Sphenopteris fontainei Sew.
Sphenopteris fittoni Sew.
Acrostichopteris ruffordi Sew.
Tæniopteris beyrichii Schenk.
Tæniopteris dawsoni Sew.
Teilhardia valdensis, gen. et sp. nov.

? Eufilicineæ.

Dichopteris delicatula, sp. nov.
Dichopteris sp., cf. *D. lævigata* (Phill.).
Weichselia mantelli (Brongn.).

CYCADOPHYTA.

BENNETTITALES.

Bennettites saxbyanus (Brown)
Williamsonia carruthersi Sew.

CYCADOPHYTA INCERTÆ SEDIS.

Androstrobus nathorsti Sew.
Bucklandia anomala (Stokes & Webb).
Fittonia ruffordi Sew.
Yatesia morrisii Carr.
Cycadolepis spp. (including *Dory-Cycadolepis* and *Eury-Cycadolepis*).
Cycadites rœmeri Schenk.
Cycadites saportæ Sew.
Dioonites dunkerianus (Gœpp.)
Dioonites brongniarti (Mant.).
Nilssonia schaumburgensis (Dunk.).
Anomozamites lyellianus (Dunk.).
Otozamites klipsteinii (Dunk.).
Otozamites gœppertianus (Dunk.).
Zamites buchianus (Ett.).
Zamites carruthersi Sew.
Pseudoctenis eathiensis (Rich.) [*? Zamites* sp., Seward (95) p. 89, fig. 5].
Ctenis sp.

CONIFERALES.

Araucarineæ.

Araucarites pippingfordensis (Ung.).
Araucarites sp.
Elatides sternbergiana (Dunk.) [*Sphenolepidium sternbergianum* Seward (95), p. 205].
Elatides curvifolia (Dunk.) [*Pagiophyllum crassifolium* Schenk, Seward (95) p. 212].

Cupressineæ.

Thuites valdensis Sew.

Abietineæ.

Pinites solmsi Sew.
Pinites dunkeri Carr.
Pinites carruthersi Gard.
Pinites ruffordi Sew.
Pityospermum sp.

Coniferales incertæ sedis.

Sphenolepidium kurrianum (Dunk.).
Brachyphyllum spinosum Sew.
Brachyphyllum obesum Heer.
Nageiopsis sp., cf. *N. heterophylla* Font.

GYMNOSPERMÆ INCERTÆ SEDIS.

Conites berryi Sew. [= *C. armatus* Seward (95) p. 222].
Becklesia anomala Sew.
Benstedtia sp. [Seward (96)].
Sewardia saportæ (Sew.) [= *Withamia saportæ*, Seward (95) p. 174.]

PLANTÆ INCERTÆ SEDIS.

Specimens described in the 'Wealden Flora' (94) p. 19 & pl. i, fig. 7, and on p. 106 of this paper.

Notes on the List of British Wealden Plants.

Chara knowltoni Sew.—Fragments of *Chara* preserved in the Purbeck chert-beds, near Swanage, have also been referred to this species.[1]

Tempskya schimperi Corda.—This species, with two others, is included provisionally in the family Schizæaceæ, on evidence which cannot be regarded as conclusive. In a recent account of a Russian species of *Tempskya* Dr. Kidston & Prof. Gwynne-Vaughan[2] contribute important information with regard to the anatomy of the stem and petiole, and discuss the affinities of the genus. The presence of a solenostele in the stem, as the authors point out, while suggesting a comparison with certain recent Schizæaceæ, as with some other ferns, is not in itself a conclusive criterion as to systematic position; but the discovery by Mr. Boodle[3] of ridged spores embedded in the tissues of the Wealden species is noted as a point in favour of, though not demonstrating, relationship to the Schizæaceæ.

Dichopteris.—The position of this genus is still undecided, and, though included in the above list in the Filicales, it has not been proved a fern.

Weichselia mantelli (Brongn.).[4]—Dr. Bommer[5] has recently published an interesting preliminary note on this characteristic Wealden plant, in which he describes some imperfectly-preserved reproductive organs, originally described from isolated specimens as *Conites minutus*[6]; he also throws fresh light on the morphology of the frond, and shows that the specimens hitherto regarded as portions of bipinnate fronds are large compound pinnæ borne in a fan-like cluster at the expanded summit of a thick petiole, the anatomy of which is described. Dr. Bommer compares *Weichselia* with the Matonineæ and Marattiaceæ, suggesting also the possibility of a Pteridosperm alliance.

Dioonites dunkerianus (Gœpp.).— Prof. Nathorst[7] draws attention to a certain resemblance between the epidermal structure of this species and that of *Pseudocycas insignis* Nath., without suggesting specific or even generic identity.

Elatides.—It should be pointed out that the reference of this genus to the Araucarineæ is based on the structure of some cones,[8] and not only on a similarity in habit of vegetative shoots. The Araucarian affinity, although very probable, cannot be regarded as definitely established.

[1] Seward (98) p. 224, fig. 45, A & B.
[2] Kidston & Gwynne-Vaughan (11).
[3] Boodle (95).
[4] = *Weichselia reticulata* (Stokes & Webb).
[5] Bommer (10).
[6] Seward (00) p. 28 & pl. iv, figs. 60–62, 64.
[7] Nathorst (07^2) p. 6.
[8] Seward (11) p. 685; Nathorst (97) p. 58.

Pinites ruffordi Sew.—For a description, with illustrations, of this species, founded on petrified wood, see Seward (96^2).

Nageiopsis sp.—The specimens on which Fontaine founded his species *N. heterophylla* are identified by Mr. Berry [1] as *N. zamioides* Font., and the genus is believed by him to be closely allied to the recent Conifer *Podocarpus*, an opinion which still lacks the support of reproductive shoots.

Benstedtia.—Dr. Marie Stopes [2] has recently shown that in some of the casts placed by me in this genus the wood consists of tracheids like those of certain Conifers (not Araucarian), and she suggests that Fliche's generic name *Coniferocaulon* should be substituted for *Benstedtia.*

Sewardia saportæ (Sew.).—Prof. Zeiller,[3] who, despite my careless employment in the 'Wealden Flora' of a generic designation (*Withamia*) already in existence, instituted the present genus, places this plant among the Cycads. While this may be its true position, we have as yet no means of deciding whether it is a Cycad or a Conifer.

The recent monograph by Mr. Berry [4] and other contributors published under the auspices of the Geological Survey of Maryland renders unnecessary a comprehensive review of the Wealden floras of the world. In this exceedingly useful and important volume Mr. Berry not only describes several new types of Potomac plants, but revises the work of previous writers and deals with the geographical distribution and geological sequence of Lower Cretaceous floras generally.

The subjoined table (p. 111) is drawn up with the view of illustrating the geographical range of some of the more widespread and better-known Wealden plants; it does not profess to show the range of plants specifically identical with the British types selected, but to express in general terms the range of species believed to be closely allied to, and in some cases specifically identical with, these types.

In endeavouring to form an opinion as to the degree of resemblance between one flora, in this case a British flora, and floras of the same or approximately the same age in other regions, the most profitable and feasible plan would seem to be to regard the plants selected for our purpose as representative types equivalent not to single species in the ordinary sense, but, as a rule, to two or more closely-allied types. A few examples may serve to explain the nature of the basis on which the table is compiled. *Equisetites lyelli* is used in a comprehensive sense, as including Equisetaceous

[1] Berry (10^2) p. 191.
[2] Stopes (11). See also Seward (96); *id.* (03) p. 35; Knowlton (11); Stopes (11^2). [3] Zeiller (00) p. 232. [4] Berry (11^2).

plants agreeing generally with Mantell's type, though by no means in all cases specifically identical with the species on which the records are founded. Similarly *Araucarites pippingfordensis* and *Pinites solmsi* [1] represent respectively Araucarian and Abietineous plants accredited to different regions, on evidence furnished by identical or closely-allied species.

In addition to the regions named at the head of the table, there are a few others from which Neocomian species have been recorded; but the number of such specimens is small, and the floras are not sufficiently important to be included in a general summary which is admittedly incomplete. A few plants have been described by Prof. Nathorst [2] from Neocomian rocks in Mexico, and it is possible that a few species recorded from New Zealand [3] are members of a Wealden flora. Neocomian species have been described from South-Western China,[4] and an imperfectly-preserved specimen from Egypt is compared with *Weichselia mantelli.*[5]

The age of the Spitsbergen and King-Charles-Land plants is considered by Prof. Nathorst to be Uppermost Jurassic, the term 'Jurassic' being understood to include Wealden floras.[6] It is generally recognized that, botanically, the limit between Jurassic and Cretaceous floras, using the terms in the ordinary stratigraphical sense, is largely conventional.[7] Prof. Nathorst also assigns the plants described by him from Franz Josef Land to the upper part of the Jurassic System.[8]

From Bornholm a few plants have recently been described [9] as probably Wealden in age, although the great majority of species from that island are from a Liassic or even Rhætic horizon.

The material described by Neumann, Zeiller, and Salfeld [10] from Peru, though small in amount, indicates the presence of a Wealden flora.

In Eastern North America [11] the Potomac Group, or at least the older plant-beds, have afforded a particularly rich harvest of Lower Cretaceous or Cretaceo-Jurassic types. On the west side are the Kootanie plants (Montana), the Shasta flora (California), the plant-beds in the Queen Charlotte Islands, and other floras described by several authors.

1 The Middle Cretaceous species *Prepinus statenensis* Jeffrey from Kreischerville, New York, is probably a closely allied type. See Hollick & Jeffrey (09) p. 19.

2 Nathorst (90^2).

3 See Seward (94) p. xxxiii.

4 Yokoyama (06).

5 Seward (07^2).

6 Nathorst (97); *id.* (10) p. 369. See also Gothan (07).

7 Van den Broeck (01) p. 199. On this subject, see an important note by Mr. Lamplugh (00).

8 Nathorst (99).

9 Bartholin (10).

10 Neumann (07); Zeiller (10); Salfeld (09).

11 For references, see Berry (11^2): also Knowlton (10); Chamberlin & Salisbury (06) vol. iii, chap. xiv.

Selected Types of British Wealden plants.	Spitsbergen; King Charles Land; Franz Josef Land.	France, Germany, Belgium, Bornholm, etc.	Portugal.	Russia.	Japan.	South Africa.	Peru.	E. North America.	W. North America.	Remarks.
Equisetites lyelli	...	+	+	+	...	...	+	+	+	
Sagenopteris mantelli	...	+	..	...	...	...	...	+	+	
Matonidium gœpperti	...	+	+	+	...	...	...	...	+?	*Matonidium* is recorded from the Shasta Formation (California) on evidence which is by no means conclusive. Fontaine in Ward (05) pl. lxv, figs. 22 & 23.
Hausmannia pelletieri	...	+	..	...	...	...	...	..	+	*Hausmannia (?) californica* Font. [Ward (05) pl. lxv, fig. 47] is founded on a fragment which may belong to a *Hausmannia* frond, but the occurrence of the genus has not been demonstrated.
Gleichenites cycadina	+	+	...	...	+	...	...	...	+	
Ruffordia gœpperti	+	+	+	+	+	...	...	+		
Cladophlebis browniana	...	+	+	+	+	+	+	+	+	
Onychiopsis mantelli	+	+	+	...	+	+	...	+		
Cladophlebis albertsii	+	+	+	+	..	...	...	+	+	
Sphenopteris fittoni	...	+	+	...	...	+	...	+		
Tæniopteris beyrichii	+	+	...	...	...	+	+	+	+	
Dichopteris delicatula	+	+	...	.	...	...	..	+		The specimen figured by Fontaine as *Gleichenia (?) gilbert-thompsoni* [Ward (05) pl. lxvi, fig. 11] very closely resembles *Weichselia*.
Weichselia mantelli	...	+	...	+	...	...	+	...	+?	
Dioonites dunkerianus	...	+	...	...	+	...	...	...	+	
Nilssonia schaumburgensis	...	+	...	...	+	...	...	+	+	
Anomozamites lyellianus	...	+			...	..		...	+	The specimen figured by Neumann as *Otozamites gœppertianus* [(07) pl. ii, fig. 3] is placed by Salfeld [(09) pl. iii, fig. 6] in *Glossozamites (?)*; it is probably a true *Otozamites*.
Otozamites gœppertianus	..	+	...	...			+		..	
Zamites buchianus	.	+	..		+	+		+	+	
Araucarites pippingfordensis	...	+	...	...	...	+	...	+	...	For the occurrence of Araucarian species in France, see Fliche (00) in addition to other sources.
Elatides curvifolia	+	+	+	+	...	...	...	+	+	
Pinites solmsi	+	+	...	...	...	...	...	+	+	
Sphenolepidium kurrianum	...	+	+	+	..	...	.	+		The specimen figured by Salfeld from Peru as *Brachyphyllum pompeckji* appears to have the habit of the Cupressineæ. Salfeld (09) pl. iv, fig. 5.
Brachyphyllum spinosum	.	+	+			+		+	.	

A glance at the table shows that, while there is a very close similarity between the Wealden flora of England and the corresponding floras in Eastern and Western North America, the number of cosmopolitan types is smaller than in the case of the Middle Jurassic floras. This may be due in part to the smaller number of records of Cretaceo-Jurassic plants, as compared with the richer and more numerous collections from Middle Jurassic strata. The contrast between Wealden and Middle Jurassic floras is comparatively small, and it is difficult to select species which in themselves are safe criteria as to the occurrence of a Wealden, as distinct from a true Jurassic, flora. *Onychiopsis mantelli*, *Weichselia mantelli*, and a few other types may be described as useful index-plants pointing to a Wealden age; but it is, as a rule, only by the examination of a fairly large number of species that any definite pronouncement is justifiable as to the value of palæobotanical data in regard to age-determination.

It must not be forgotten that there are several Wealden species recorded from North-Western Germany, the Arctic regions, and elsewhere, which have not as yet been discovered in the English area. The Ginkgoales are a case in point: the genera *Ginkgo* and *Baiera*, both fairly abundant in the Jurassic vegetation of East Yorkshire, have not been found in the Wealden of England. The fact that these plants existed in the Kimmeridgian Epoch in Scotland, as also in the Wealden flora of Germany, favours the view that their absence from the list of English species (p. 107) is one of the many lacunæ which further search may be expected to fill.

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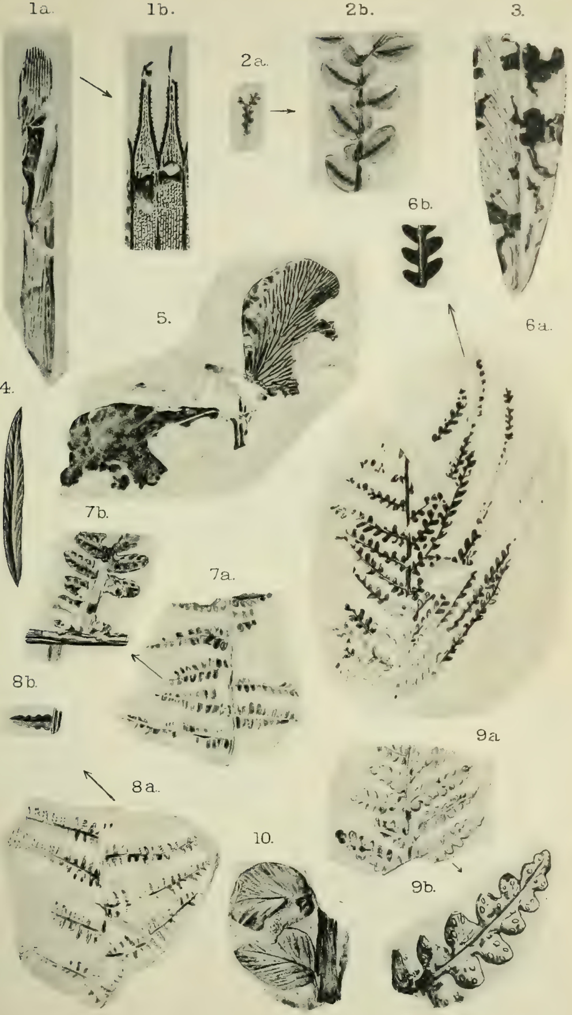
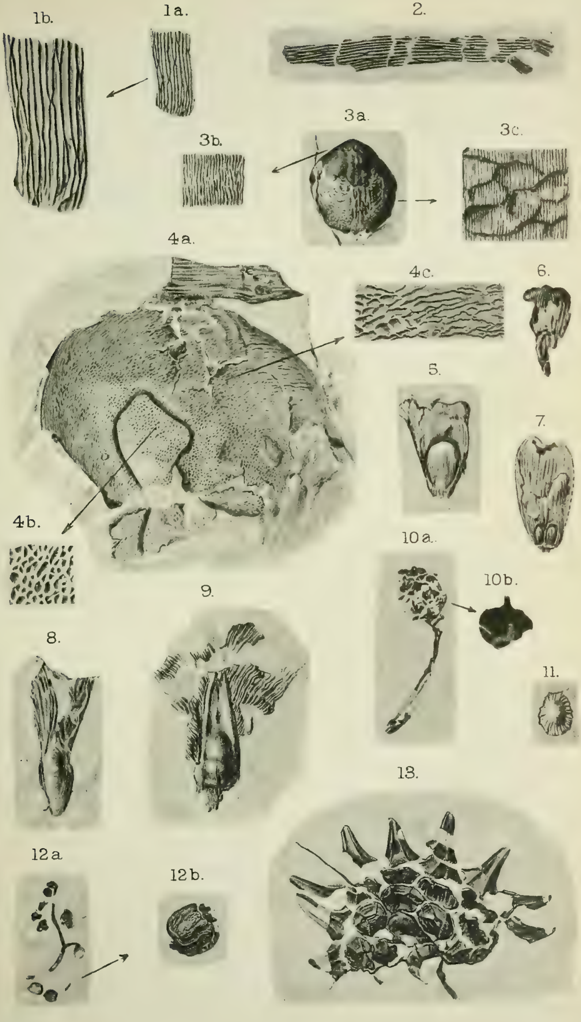


T A. Brock, Del. Bemrose, Collo., Derby.

EQUISETITES, LYCOPODITES, SAGENOPTERIS, DICHOPTERIS, TEILHARDIA, AND FILIX incert. Sed.



T. A. Brock, Del.

Bemrose. Collo., Derby

CTENIS, EURY-CYCADOLEPIS, ARAUCARITES, PINITES, SPHENOLEPIDIUM, PELLETIERIA, CONITES, ETC.

Fig. 1.

Fig. 2

W. Tams, Photo.

Bemrose, Collo., Derby.

CLADOPHLEBIS BROWNIANA (DUNK.)

W. Tams, Photo.
Bemrose, Collo, Derby.

HAUSMANNIA; MATONIDIUM; PELLETIERIA; APHLEBIA;
AND EURY-CYCADOLEPIS.

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EXPLANATION OF PLATES XI–XIV.

[The specimens are all in the British Museum (Natural History). In cases where the drawings are larger than natural size the magnification is stated. The numerals in parentheses are the Museum Register-numbers.]

PLATE XI.

Figs. 1 *a* & 1 *b*. *Equisetites lyelli* (Mant.). (V 12303.) 1 *b*×8. (See p. 85.)
Figs. 2 *a* & 2 *b*. *Lycopodites teilhardi*, sp. nov. (V 12304.) 2 *b*×6. (See p. 86.)
Figs. 3 & 5. *Sagenopteris mantelli* (Dunk.). (V 12305, V 12306.) (See p. 87.)
Fig. 4. *Sagenopteris acutifolia* Sew. (V 2344.) (See p. 88.)
Figs. 6 *a* & 6 *b*. *Dichopteris delicatula*, sp. nov. (V 12307.) 6 *b*×3. (See p. 98.)
Figs. 7 *a*–9 *b*. *Teilhardia valdensis*, gen. et sp. nov. (V 3743.) 7 *b*, 8 *b*, & 9 *b*, all×3. (See p. 96.)
Fig. 10. *Filix incertæ sedis*. (V 2735.) (See p. 97.)

PLATE XII.

Figs. 1 *a*–2. *Ctenis* sp. (V 2814.) 1 *b*×2. (See p. 101.)
Figs. 3 *a*–4 *c*. *Eury-Cycadolepis* sp. (V 12308 & V 12309.) 3 *b* & 3 *c*×6; 4 *a* half of the natural size; 4 *b* & 4 *c*×1½. (See p. 101.)
Fig. 5. *Araucarites* sp. (V 12310.) (See p. 104.)
Figs. 6 & 7. *Pinites* sp., cf. *P. dunkeri* Carr. (V 12311 & 12312.) (See p. 105.)
Figs. 8 & 9. *Planta incertæ sedis, α*. (V 12313 & 12314.) (See p. 106.)
Figs. 10 *a* & 10 *b*. *Sphenolepidium kurrianum* (Dunk.). (V 12315.) 10 *b*×3. (See p. 105.)
Fig. 11. *Planta incertæ sedis, β*. (V 12314.) (See p. 106.)
Figs. 12 *a* & 12 *b*. *Pelletieria valdensis*, gen. et sp. nov. (V 2329.) 12 *b*×4. (See p. 91.)
Fig. 13. *Conites berryi*, sp. nov. (V 3747.) (See p. 103.)

PLATE XIII.

Figs. 1 & 2. *Cladophlebis browniana* (Dunk.). (V 12322.) (See p. 95.)

PLATE XIV.

Figs. 1–3. *Hausmannia pelletieri*, sp. nov. (V 12316–V 12318.) 1×2; 2×3. (See p. 89.)
Fig. 3 *a*. *Matonidium gœpperti* (Ett.). (V 12316.) (See p. 89.)
Fig. 4. *Aphlebia* sp. (V 3714.) (See p. 98.)
Fig. 5. *Pelletieria valdensis*; spore highly magnified. (V 2329.) (See p. 92.)
Fig. 6. *Eury-Cycadolepis* sp.; cuticle highly magnified. (V 12319.) (See p. 103.)

DISCUSSION.

Mr. CHARLES DAWSON thanked the Author on behalf of Father Félix Pelletier and Father P. Teilhard de Chardin for his kindness in undertaking the determination and description of the Wealden plants collected by them from the Fairlight Clays at Hastings.

For the last four years these French gentlemen had been staying at the Jesuit College at Ore, Hastings, and had devoted nearly the whole of their spare time to the collection of fossils from the Hastings and Purbeck Beds. They had displayed an immense amount of industry and perception, and had brought together a most interesting and valuable collection.

A chance meeting with them by the speaker had enabled him to assist them in the determination of many of their specimens by frequent reference to the British Museum, to which Dr. A. Smith Woodward had given every encouragement. The speaker was glad to say that, at the conclusion of their visit to England, Fathers Pelletier and Teilhard de Chardin had most generously allowed Dr. Woodward to make a selection of any specimens which he wished to have for the British Museum (Natural History). The remainder of their specimens they presented to the Hastings Museum, which contains a collection of fossil Wealden plants only second in importance to the National collection.

Mr. Dawson observed as to the fossil plants now described, that it was rather remarkable to find side by side on one piece of Wealden rock remains of fossil ferns, *Matonidium* and *Hausmannia*, genera which have long ceased to exist in the Northern Hemisphere, but are very closely allied to the modern *Matonia* and *Dipteris* respectively, which now grow side by side on Mount Ophir in the Malay Peninsula. The Author had very ably dealt with these comparisons in his recent work, 'Links with the Past in the Plant World.'

Dr. W. F. Hume remarked that Father Teilhard de Chardin first developed his geological enthusiasm in Egypt, and congratulated British geology on his transference to England, as also on the fact that his materials had been described by Prof. Seward.

The President (Dr. A. Strahan) congratulated the Society on having heard a brilliant exposition of a difficult and highly technical subject. Bearing in mind the stratigraphical relationships of the Wealden, he was relieved to hear that there were some plants which served to distinguish that formation from the Jurassic.

The Author expressed gratitude to the Fellows for their cordial reception of his paper; he thanked Mr. Dawson for the very great assistance which he had rendered both personally and through Father Pelletier and Father Teilhard de Chardin towards the investigation of the Wealden Flora. He adduced some additional statements in support of the view, with which he agreed, that in many instances Southern countries are the refuges of Mesozoic types which were gradually driven across the Equator.

8. *On the* DISCOVERY *of a* PALÆOLITHIC HUMAN SKULL *and* MANDIBLE *in a* FLINT-BEARING GRAVEL OVERLYING *the* WEALDEN (HASTINGS BEDS) *at* PILTDOWN, FLETCHING (SUSSEX). By CHARLES DAWSON, F.S.A., F.G.S., and ARTHUR SMITH WOODWARD, LL.D., F.R.S., Sec.G.S. *With an* APPENDIX *by* Prof. GRAFTON ELLIOT SMITH, M.A., M.D., F.R.S. (Read December 18th, 1912.)

I. GEOLOGY AND FLINT-IMPLEMENTS. [C. D.]

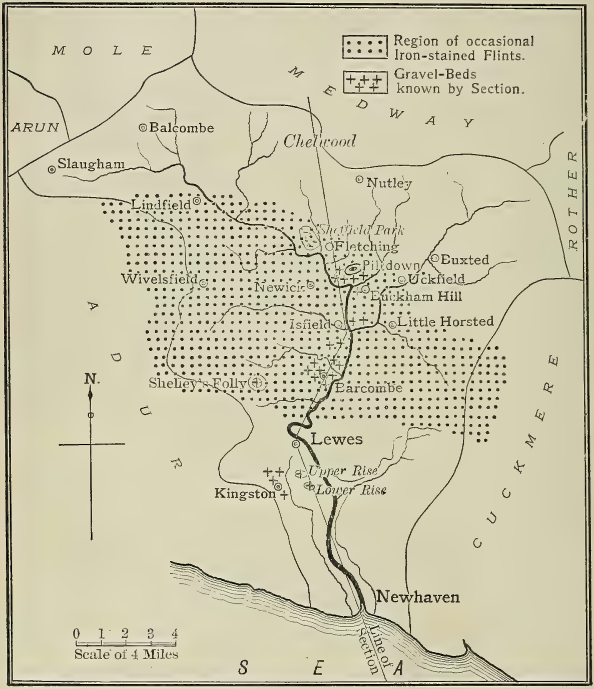
[PLATES XV–XVII.]

SEVERAL years ago I was walking along a farm-road close to Piltdown Common, Fletching (Sussex), when I noticed that the road had been mended with some peculiar brown flints not usual in the district. On enquiry I was astonished to learn that they were dug from a gravel-bed on the farm, and shortly afterwards I visited the place, where two labourers were at work digging the gravel for small repairs to the roads. As this excavation was situated about 4 miles north of the limit where the occurrence of flints overlying the Wealden strata is recorded, I was much interested, and made a close examination of the bed. I asked the workmen if they had found bones or other fossils there. As they did not appear to have noticed anything of the sort, I urged them to preserve anything that they might find. Upon one of my subsequent visits to the pit, one of the men handed to me a small portion of an unusually thick human parietal bone. I immediately made a search, but could find nothing more, nor had the men noticed anything else. The bed is full of tabular pieces of ironstone closely resembling this piece of skull in colour and thickness; and, although I made many subsequent searches, I could not hear of any further find nor discover anything—in fact, the bed seemed to be quite unfossiliferous.

It was not until some years later, in the autumn of 1911, on a visit to the spot, that I picked up, among the rain-washed spoil-heaps of the gravel-pit, another and larger piece belonging to the frontal region of the same skull, including a portion of the left superciliary ridge. As I had examined a cast of the Heidelberg jaw, it occurred to me that the proportions of this skull were similar to those of that specimen. I accordingly took it to Dr. A. Smith Woodward at the British Museum (Natural History) for comparison and determination. He was immediately impressed with the importance of the discovery, and we decided to employ labour and to make a systematic search among the spoil-heaps and gravel, as soon as the floods had abated; for the gravel-pit is more or less under water during five or six months of the year. We accordingly gave up as much time as we could spare since last spring (1912), and completely turned over and sifted what spoil-

material remained; we also dug up and sifted such portions of the gravel as had been left undisturbed by the workmen.[1]

Fig. 1.—*Plan of the basin of the Sussex Ouse, showing the distribution of iron-stained flints and flint-bearing gravels.*



For many years the harder layers of this gravel-bed have been intermittently worked for farm-road material, as shown by old excavations which are now overgrown, but are traceable over the adjoining fields; and there is known to exist a gravel-bed of appreciable thickness extending over several neighbouring acres. Where the beds have been naturally denuded, a large number of

[1] These excavations were undertaken with the kind consent of the Lord of the Manor, Mr. G. M. Maryon-Wilson, and of Mr. Robert Kenward, tenant of the farm, to whom the Authors wish to record their grateful acknowledgments.

the brown and red flints and the ironstone gravel are to be seen overlying the plough-lands in all directions.

At Piltdown the gravel-bed occurs beneath a few inches of the surface-soil, and varies in thickness from 3 to 5 feet; it is deposited upon an uneven bottom, consisting of hard yellow sandstone of the Tunbridge Wells Sands (Hastings Beds). It is composed for the most part of dark-brown Wealden ironstone pebbles, but is mixed, to the extent of about a sixth of the mass, with angular brown flints, a large proportion of which are tabular in form.[1] Occasional cherts and quartzite pebbles also occur, but there are no recognizable Eocene pebbles.[2] The flints vary from 6 or 7 inches in length by 3 or 4 inches in width, down to a very fine gravel or sand. Portions of the bed are rather finely stratified, and the materials are usually cemented together by iron oxide, so that a pick is often needed to dislodge portions—more especially at one particular horizon near the base. It is in this last-mentioned stratum that all the fossil bones and teeth discovered *in situ* by us have occurred. The stratum is easily distinguished in the appended photograph (Pl. XV) by being of the darkest shade and just above the bed-rock.

The gravel is situated on a well-defined plateau of large area, lying above the 100-foot contour-line, averaging about 120 feet at Piltdown, and lies about 80 feet above the level of the main stream of the Ouse. The river has cut through the plateau, both with its main stream and its principal branch, which is called the Uckfield River.

Speaking generally, the remains of this plateau, of which that at Piltdown is merely a part, can in places be traced along a line drawn through Lindfield, Sheffield Park, Buckham Hill, Uckfield, and Little Horsted and southwards, broadening outwards towards the Chalk Escarpment. In fact, the whole country lying between the base of the Wealden Anticline and the Chalk Escarpment presents the appearance of one large low plateau or former base-level plane dissected by the Ouse and its tributary streams.

Remnants of the flint-gravels and drifts constantly occur above the 100-foot contour-line, and upon the slopes, down which they are trailing towards the river and streams.

These flint-bearing gravels and drifts have not been mapped or otherwise recorded before in the Ouse Valley, north of the boundary between the Wealden Clay and the Hastings Beds, which runs immediately south of Isfield. Up to the latter point they are

[1] There is a tendency among these tabular flints to weather into a prismatic or polyhedral form. One specimen shows a column 2 inches in length. The prismatic structure is well shown in figs. 2, 6, 7, & 9 of Pl. XVII. Most of the nodular flints, formerly existing, appear to have disintegrated.

[2] Dr. J. V. Elsden writes that Tertiary pebbles are found in the Ouse gravels on the south near Lewes. Eocene pebbles occur in a thin bed east of the Race Stand, on the hill above Lewes; and a similar band is to be seen about 15 feet down the cliff, near the Coastguard Station at Newhaven. See Q. J. G. S. vol. xliii (1887) pp. 646–47.

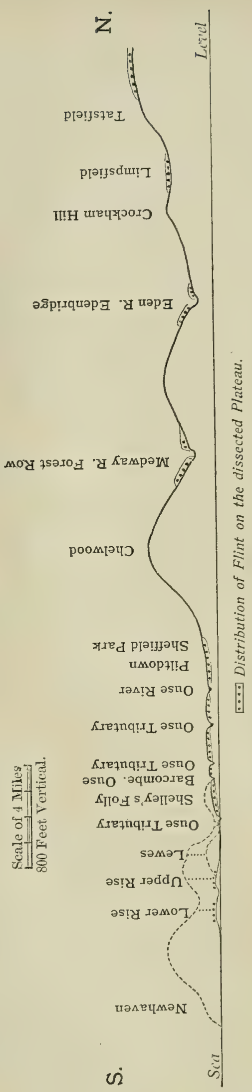


Fig. 2.—*Diagrammatic section of the Weald, showing the low plateau on the south capped by flint-bearing gravels.*

[The thickness of the gravels is much exaggerated in the above section.]

common, and they have been described by Mantell,[1] Topley,[2] and Dr. Elsden[3]; but both Topley and those who have followed him use almost the same words, namely, that

> 'on entering the Hastings Beds country, flints no longer occur either on the surface, or in the river-gravel.'[4]

However, in the Tunbridge Wells Sands (Hastings Beds), out of a thousand fields of which I have a record, that have all been thrice tested by means of boreholes to the depth of 3 feet, fifty fields or more furnish abundant evidence of the presence of these brown and red flints. They are present over the Wadhurst Clay between Isfield and Buckham Hill, but the boundary of this stratum is faulted. I have only found them to occur as small fragments, and seldom on the older Wealden Beds of the higher levels within the Ouse watershed.

The field-borings go to show that in the greater part of the area over which the flint is distributed, the gravel seldom occurs within 3 feet of the surface in beds of appreciable thickness; but trial-borings along the slopes reveal considerable deposits of gravel, containing small

[1] 'Geology of the South-East of England' 1833, p. 28.
[2] 'Geology of the Weald' Mem. Geol. Surv. 1875, pp. 202, 273, 287–88, 292.
[3] Q. J. G. S. vol. xliii (1887) p. 646.
[4] See also A. J. Jukes-Browne, 'Building of the British Isles' 3rd ed. (1911) p. 426; and A. C. Ramsay, 'Physical Geology, &c.' 5th ed. (1878) p. 344.

fragments of iron-stained flint, 6 feet and more beneath the surface.

Considering the amount of material excavated and sifted by us, the specimens discovered were numerically small and localized.

Apparently the whole or greater portion of the human skull had been shattered by the workmen, who had thrown away the pieces unnoticed. Of these we recovered, from the spoil-heaps, as many fragments as possible. In a somewhat deeper depression of the undisturbed gravel I found the right half of a human mandible. So far as I could judge, guiding myself by the position of a tree 3 or 4 yards away, the spot was identical with that upon which the men were at work when the first portion of the cranium was found several years ago. Dr. Woodward also dug up a small portion of the occipital bone of the skull from within a yard of the point where the jaw was discovered, and at precisely the same level. The jaw appeared to have been broken at the symphysis and abraded, perhaps when it lay fixed in the gravel, and before its complete deposition. The fragments of cranium show little or no sign of rolling or other abrasion, save an incision at the back of the parietal, probably caused by a workman's pick.

A small fragment of the skull has been weighed and tested by Mr. S. A. Woodhead, M.Sc., F.I.C., Public Analyst for East Sussex & Hove, and Agricultural Analyst for East Sussex. He reports that the specific gravity of the bone (powdered) is 2·115 (water at 5° C. as standard). No gelatine or organic matter is present. There is a large proportion of phosphates (originally present in the bone) and a considerable proportion of iron. Silica is absent.

Besides the human remains, we found two small broken pieces of a molar tooth of a rather early Pliocene type of elephant,[1] also a much-rolled cusp of a molar of *Mastodon*, portions of two teeth of *Hippopotamus*, and two molar teeth of a Pleistocene beaver. In the adjacent field to the west, on the surface close to the hedge dividing it from the gravel-bed, we found portions of a red deer's antler and the tooth of a Pleistocene horse. These may have been thrown away by the workmen, or may have been turned up by a plough which traversed the upper strata of the continuation of this gravel-bed. Among the fragments of bone found in the spoil-heaps occurred part of a deer's metatarsal, split longitudinally. This bone bears upon its surface certain small cuts and scratches, which appear to have been made by man. All the specimens are highly mineralized with iron oxide.

[1] It is stated by R. A. C. Godwin-Austen (Q. J. G. S. vol. vii, 1851, p. 288) and E. Dixon ('Geology of Sussex' 2nd ed. 1878, p. 110, n.) that remains of 'the large mammalia,' including teeth of elephants, were found in the gravels at Barcombe, 6 or 7 miles south of Piltdown. It is not known to what genera or species these belonged; but, as they are referred to as 'the Asiatic Elephant,' they were probably the true form of *Elephas* and not *Mastodon*, though it is possible that some may have belonged to the species akin to *E. meridionalis*. Specimens from this bed are not known to have been preserved, but they probably belonged to the Pleistocene age.

Flint-Implements.

The brown flints appear to be in every way similar to the plateau flints of Ightham (Kent), and generally to those of the High-Plateau gravels of the North and South Downs. There is the same appearance of tabular and prismatic structure, 'frost fractures,' thick iron-stained patina, and often the same tendency to assume the well-known 'Eolithic' forms (Pl. XVII). There also occur more occasionally certain brilliantly-coloured iron-red flints, presumably more highly oxidized than the prevailing flints, which are of a brown colour. Among the flints we found several undoubted flint-implements,[1] besides numerous 'Eoliths.' The workmanship of the former (Pl. XVI) is similar to that of the Chellean or pre-Chellean stage[2]; but in the majority of the Piltdown specimens the work appears chiefly on one face of the implements. They have been very slightly rolled or worn, and, although iron-stained, their patina is not so strong and thick as that of the other flints in the bed. Their form is thick, and the flaking is broad and sparing, the original 'bark,' or surface, of the flint frequently remaining at the grasp, the whole implement thus having a very rude and massive form. Some of them were found on the surface of a ploughed field adjacent to the gravel-bed, which is also strewn with brown and red flints; but, on the surface of the neighbouring plough-lands there occur, in places, flint-implements of various ages, all more or less stained with the iron which abounds in this part of the Weald. In our plates we have confined ourselves to the representation of flints found in the gravel-pit at Piltdown.

As to the 'Eoliths,'[3] it is necessary to speak of them with due reserve and caution. The commonest types belong to the 'borer' and 'hollow-scraper' forms. They occur both in the gravel-bed and on the surface of the plough-lands, and are found in both a rolled and an unrolled (or very slightly rolled) condition. Pl. XVII

[1] Father P. Teilhard, S.J., who accompanied us on one occasion, discovered one of the implements (Pl. XVI, fig. 2) *in situ* in the middle stratum of the gravel-bed, also a portion of the tooth of a Pliocene elephant (Pl. XXI, fig. 2) from the lowest bed.

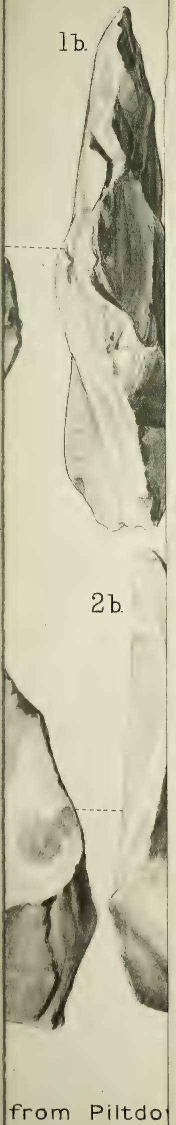
[2] Implements of this stage are difficult to classify with certainty, owing to the rudeness of their workmanship. The Piltdown specimens may be compared with an example from Chelles, figured in Piette's 'L'Art pendant l'Âge du Renne' p. 36. They resemble certain rude implements occasionally found on the surface of the Chalk Downs near Lewes, which are not iron-stained.

[3] The flints, which so nearly resemble those of the plateau gravels of the North Downs, occur sporadically over the South Downs and over many of the older rocks of the Weald. They have lately been discovered in the fields close to the signal-station at Fairlight Down on the summit of the Wealden Anticline (base of the Ashdown Beds and top of the Fairlight Clay) by Mr. W. Ruskin Butterfield, of the Hastings Museum. They occur in the surface-deposits only, mingled with Neolithic implements and certain iron-stained implements which Mr. Reginald Smith, F.S.A., identifies with the early cave types. The last-named are not rolled. Mr. Lewis Abbott, F.G.S., has given considerable attention to this subject, and possesses a large series of implements which we may hope will some day be described in detail.

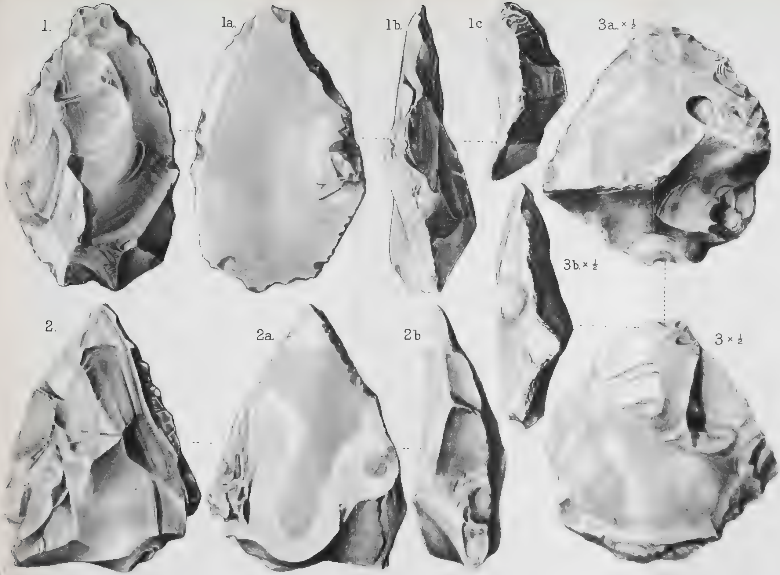
J. Frisby photo.

FLINT-BEARING GRAVEL-BED OVERLYING THE TUNBRIDGE WELLS SANDS (HASTINGS BEDS),
AT PILTDOWN, FLETCHING, SUSSEX.

[The darkest stratum resting on the bed-rock in the section is that from which the skull and mandible were obtained.]



from Piltdo



G. M. Woodward, del.

Bemrose, Collo., Derby

PALÆOLITHS from Piltdown (Sussex).

from Piltdo

G. M. Woodward, del.

Bemrose Collo, Derby

"EOLITHS" from Piltdown (Sussex).

illustrates both of these classes of 'Eoliths.' Whether natural or artificial, the fractures appear to have been largely governed by the prismatic structure of the flint. Both the rolled and the unrolled 'Eoliths' are deeply stained and patinated, but the former to a much greater extent than the latter.

Conclusions.

In conclusion, we may briefly consider the age of the human skull and mandible.

It is clear that this stratified gravel at Piltdown is of Pleistocene age, but that it contains, in its lowest stratum, animal remains derived from some destroyed Pliocene deposit probably situated not far away, and consisting of worn and broken fragments. These were mixed with fragments of early Pleistocene mammalia in a better state of preservation, and both forms were associated with the human skull and mandible, which show no more wear and tear than they might have received *in situ*. Associated with these animal remains are 'Eoliths,' both in a rolled and an unrolled condition; the former are doubtless derived from an older drift, and the latter in their present form are of the age of the existing deposit. In the same bed, in only a very slightly higher stratum, occurred a flint-implement (Pl. XVI, fig. 2), the workmanship of which resembles that of implements found at Chelles; and among the spoil-heaps were found others of a similar, though perhaps earlier, stage.

From these facts it appears probable that the skull and mandible cannot safely be described as being of earlier date than the first half of the Pleistocene Epoch. The individual probably lived during a warm cycle in that age.

EXPLANATION OF PLATES XV–XVII.

Plate XV.

Flint-bearing gravel-bed overlying the Tunbridge Wells Sands (Hastings Beds) at Piltdown, Fletching, Sussex. The darkest stratum resting on the bed-rock in the section is that from which the skull and mandible were obtained.

Plate XVI.

Fig. 1. Palæolithic implement, well worked on one face (1); a simple flake on the other face (1 *a*); twisted in edge-view (1 *b*); and thickest at the broader end (1 *c*). Natural size.

2. Palæolithic implement, worked on one face (2); simply flaked on the other face (2 *a*); seen in edge-view (2 *b*) to be relatively thick at the broader end, with remains of the flint-nodule from which it was made. Natural size.

3. Palæolithic implement, showing much of the outer surface of the original flint-nodule on its well-flaked face (3); simply flaked on the other face (3 *a*); and very unsymmetrical in basal view (3 *b*). Half of the natural size.

[All the above implements are iron-stained.]

PLATE XVII.

Figs. 1–3. 'Eoliths' of the bow-shaped and double-edged scraper type. (Figs. 1 & 3 are rolled, fig. 2 is unrolled.)
4 & 5. Similar 'Eoliths' (unrolled) from Fairlight, near Hastings.
6 & 7. 'Eoliths' of the drill or borer type. (Fig. 6 is rolled, fig. 7 is unrolled.)
8–10. 'Eoliths' of the crescent-shaped scraper type. (Figs. 8 & 9 are rolled, fig. 10 is unrolled.)
Fig. 11. 'Eolith' (rolled), showing considerable chipping around its point.

[All the figures are of the natural size; and all the flints which they represent are deeply stained with iron.]

II. DESCRIPTION OF THE HUMAN SKULL AND MANDIBLE AND THE ASSOCIATED MAMMALIAN REMAINS. [A. S. W.]

[PLATES XVIII–XXI.]

The Human Skull and Mandible.

THE human remains comprise the greater part of a brain-case and one ramus of the mandible, with lower molars 1 and 2. All the bones are normal, with no traces of disease, and they have not been distorted during mineralization.

Of the brain-case there are four pieces (reconstructed from nine fragments) sufficiently well preserved to exhibit the shape and natural relations of the frontal, parietal, occipital, and temporal bones, and to justify the reconstruction of some other elements by inference. These bones are particularly noteworthy for their thickness, and for the depth of the branching grooves which are impressed on their cerebral face by the meningeal vessels. The thickening is due to the great development of the finely cancellated diploe, the outer and inner tables of the bone being everywhere comparatively thin. The thickest point is at the internal occipital protuberance, where the measurement is 20 millimetres. A thickness of 11 or 12 mm. is attained at the postero-lateral angle of the left parietal and at the horizontal ridges of the occipital; while a thickness of 10 mm. is observable along the greater part of the fractures of the parietals and frontals. Compared with the corresponding portion on the opposite side, the postero-lateral region of the right parietal is rather thin, its thickness at the lambdoid suture being 8 to 9 mm. It is interesting to add that the average thickness of modern European skulls varies between 5 and 6 mm.; while that of the Australian skulls [1] and of the Mousterian skull from La Chapelle-aux-Saints (France) [2] is from 6 to 8 mm.

[1] W. J. Sollas, Phil. Trans. Roy. Soc. vol. cxcix B (1908) p. 319.
[2] M. Boule, 'L'Homme Fossile de La Chapelle-aux-Saints' Ann. Paléont. vol. vi (1911) p. 20.

The largest continuous portion of the brain-case comprises the left side of the frontal and parietal regions, extending upwards just over the middle line both in the hinder part of the frontal and near the lambdoid suture of the parietal. The position of the middle line is indicated by the impression of the longitudinal sinus on the cerebral face of the bone at both these points, and by a slight longitudinal ridge along the outer face at the hinder end of the parietal region. The left temporal bone is nearly complete and beautifully preserved, lacking only the upper portion of the squamous wing. At one point it articulates perfectly with the squamous suture of the parietal, and the impressions of the meningeal vessels of the parietal are directly continued on its cerebral face, so that this bone can be assigned to its true position. The left side of the brain-case thus formed has no point of contact with the other two pieces of bone; but one of these is the greater part of the right parietal, extending from the lambdoid suture behind to the anterior end of the squamous suture in front, and so completely symmetrical with the left parietal that its exact position can be determined by measurement. The fourth piece of the brain-case is the middle region of the occipital bone, with a trace of the border of the foramen magnum below and a short extension as far as the lambdoid suture in one part of the right side above. The occipital and the right parietal thus come into direct contact for an extent of about 20 mm. The greater portion of the brain-case may, therefore, be reconstructed without any hypothetical restoration: the only serious deficiency being the middle portion of the frontal region above the supraorbital ridge. Such a reconstruction, with a justifiable amount of modelling, has been skilfully made by Mr. Frank O. Barlow in the Palæontological Laboratory of the British Museum, and this is shown from four aspects, with a longitudinal median section, in Pl. XVIII, figs. 1–4, and text-fig. 3 (p. 126). The actual pieces of bone are indicated by a dark tint, and the modelled portions by a lighter tint, while the hypothetical part is white.

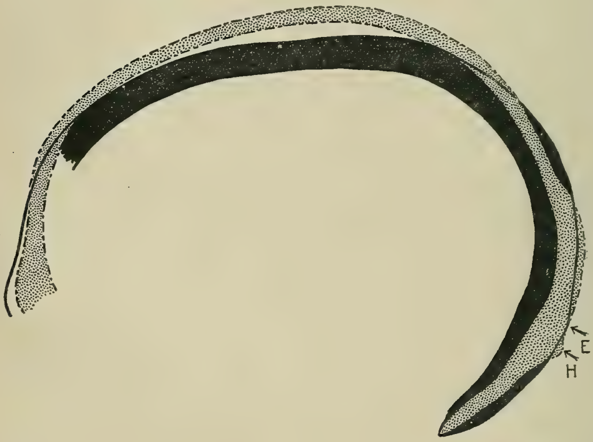
As seen from above (norma verticalis, Pl. XVIII, fig. 1), the cranium is very wide posteriorly, measuring 150 mm. across its widest part just behind the malar arch, and tapering forwards to a slight constriction behind the supraorbital ridge, where its width is 112 mm. The total length from the middle of the supraorbital ridge (glabella) to the external occipital protuberance (inion) is a little uncertain, owing to the hypothetical restoration of the middle of the frontals, but it measures probably 190 mm. The cephalic index may, therefore, be regarded as 78 or 79. Owing to the constriction of the frontal region, the malar arch is visible from above.

In anterior view (norma facialis, Pl. XVIII, fig. 2), the relative narrowness of the frontal region is well shown, and the roof is seen to rise to the vertex at the widest part of the skull. In side view (norma lateralis, Pl. XVIII, fig. 3), this upward slope is still better seen, and the steeply-curved frontal contour is especially

noteworthy. The external occipital protuberance (inion) seems to form the hindmost point of the cranium, though the portion of the occipital immediately above it is in an almost vertical plane.

In back view (norma occipitalis, Pl. XVIII, fig. 4), the contour of the skull is very remarkable. It is relatively low and wide, and gently arched above, with the sides flattened in their upper half, and the mastoid region either vertical or slightly inclined inwards.

Fig. 3.—*Sagittal section of the Piltdown skull (black) superposed on that of a skull from Lewes Levels (dotted), half of the natural size.* E=*inion of the Piltdown skull;* H=*inion of the Lewes skull.*



The capacity of the brain-case cannot, of course, be exactly determined; but measurements both by millet-seed and by water show that it must have been at least 1070 c.c., while a consideration of the missing parts suggests that it may have been a little more. It therefore agrees closely with the capacity of the brain-case of the Gibraltar skull, as determined by Prof. Keith,[1] and equals that of some of the lowest skulls of the existing Australians. It is much below that of the Mousterian skulls from Spy[2] and

[1] A. Keith, 'Ancient Types of Man' 1911, p. 125.
[2] *Id. ibid.* p. 112.

La Chapelle-aux-Saints,[1] which have a brain-case larger than that of the average modern civilized man.

The principal characters of the brain, so far as they can be observed in a cast of the cranial cavity, are described in an appendix to this paper by Prof. G. Elliot Smith (see p. 145).

A detailed examination of the several bones of the skull is interesting, as proving the typically human character of nearly all the features that they exhibit. The only noteworthy reminiscences of the ape are met with in the upward extension of the temporal fossæ, and in the low and broad shape of the occipital region.

The frontal region (Pl. XIX, figs. 1, 1 *a*, & 1 *b*) is complete on the left side and in its upper middle portion, showing that the frontal eminence is regularly and steeply rounded, and separated from the temporal fossa by a sharp ridge, which extends upwards as far as the coronal suture. This ridge (*t.*) approaches nearest to its fellow of the opposite side at its upper end, where it is continued by the curved groove on the parietal, which trends still farther towards the middle line. At its lower end the ridge passes outwards on to the external angular process (*e.a.p.*), which is short and directly continuous with the slope of the frontal eminence, not separated from this by any depression. The facette for the malar bone (*m.f.*) is well preserved; part of the smooth concave roof of the orbit is seen (fig. 1 *b*, *orb.*); and the sharp supraorbital border is but slightly abraded. It is, therefore, clear that there cannot have been any prominent or thickened supraorbital ridge, and the missing region above the glabella may be restored on the plan of an ordinary modern human skull. The median frontal (metopic) suture is completely obliterated, so far as the bone is preserved above; but a fractured surface shows that the short fronto-alisphenoid suture (*s.f.*) was only closed in its deeper half, while the coronal suture is still just visible on the wall of the temporal fossa and is conspicuous on the cranial roof. The coronal suture (*cor.*) is remarkably complicated, and its tortuous folds are seen to occupy a transversely-elongated shallow depression immediately above the limit of the temporal fossa. The total length of the frontal region along the metopic line, from the glabella to the middle of the coronal suture (bregma), must have been from 120 to 130 mm.; while its maximum width at the external angular processes is 125 mm.

Immediately behind the middle of the coronal suture the parietal region is distinctly flattened; but as it expands backwards the roof soon rises to the broad rounded vertex already mentioned, and there is a faint trace of a longitudinal median ridge near the hinder (lambdoid) border of the bone. The parietal boss or eminence is conspicuous on each side above the hinder end of the squamous suture; and this boss forms the apex of a large flattened triangular area, of which the base-line is at the lambdoid suture. The flattening just mentioned is of the same shape on each

[1] M. Boule, L'Anthropologie vol. xx (1909) p. 264.

side, and the conspicuous lines marking the upper boundaries of the temporal fossæ are also clearly symmetrical with reference to the long axis of the skull. The upper line, indicating the upper limit of the temporal fascia or aponeurosis, curves upwards at one point to a distance of 36 mm. from the middle line of the cranial roof; while the lower line, which marks the border of the temporal muscle itself, rises to a maximum height of 32 mm. above the summit of the squamous suture, and curves downwards behind along the antero-inferior edge of the parietal flattening already described. The median parietal (sagittal) suture is completely obliterated; but the lambdoid suture is open, and its outer lateral portion is shown to have been deeply serrated or complicated. The mastoid and squamous suture is open throughout its length, and the squamous portion is as well arched as in a typical modern human skull. The antero-inferior angle of the bone seems to have been almost excluded from articulation with the alisphenoid. The cerebral face, though deeply impressed with the grooves for the meningeal vessels, bears no distinct marks of the Pacchionian bodies. The length of the parietal region along the line of the sagittal suture is 120 mm.; while the total length of its border at the lambdoid suture is about 210 mm.

The occipital bone (Pl. XX, figs. 1, 1 *a*, & 1 *b*) is remarkable, both for its great width and for the relatively large extent and flatness of its smooth upper squamous portion. The depth of this upper portion, from the lambda to the external occipital protuberance, is 55 mm.; while the total length of the curve from the lambda to the middle of the hinder border of the foramen magnum (opisthion, *f.mag.*), is only 110 mm. The external occipital protuberance (*e.o.p.*) is distinctly marked, about twice as wide as deep; while the ridges of the superior (*u.c.l.*) and inferior (*l.c.l.*) curved lines, the median occipital crest (*e.o.c.*), and the other usual irregularities for muscle-attachments are also conspicuous. Above the occipital protuberance may be seen faintly the linea suprema (*l.s.*). The cerebral face of the bone (fig. 1 *a*) is interesting as showing the unsymmetrical character of the cerebellum—a condition common in modern man of both low and high degree. The grooved horizontal ridge (*si.*) on the right side of the vertical median ridge is completely above that on the left side, so that the upper surface of the tentorium over the cerebellum (*cb.*) on this side would be about 15 mm. above that on the left side. It is also important to observe that the external occipital protuberance is below the upper limit of the tentorium, as in modern man: not raised above it, as in the skull of Mousterian man.

The left temporal bone is excellently preserved, lacking only some of the upper part of the squamous wing (Pl. XIX, figs. 2, 2 *a*, 2 *b*, & 2 *c*). It is typically human in every detail, and corresponds more closely with the same bone in a comparatively modern human skull from an alluvial deposit near Lewes (Brit. Mus. 7571), than with that in the skull of an existing Melanesian from the

Chatham Islands (Brit. Mus. 91.1.20.1). The mastoid portion has no conspicuous extension on the occipital plane, and though its process (*mast.*) is rather small, this is of the characteristic shape and relations, with a deep impression on its inner side for the origin of the digastric muscle. The supramastoid ridge on the outer face behind the malar arch is an irregularly-rounded boss. The malar arch (*mal.*) arises in the usual form from the squamous part of the bone, and the glenoid cavity (*gl.*) is as deep as the deepest observable in modern man, with a transversely-extended hollow at the bottom slightly overhung by the anterior ginglymoid surface. There is no 'spina glenoidalis,' such as is described by Prof. Boule in the Mousterian skull from La Chapelle-aux-Saints.[1] A distinct though small postarticular process (*p.a.p.*) occurs, separating the upper part of the tympanic from the glenoid cavity; and the long axis of the ovoid opening of the external auditory meatus (*e.a.m.*) is inclined downwards and backwards as in modern man, not forwards as in the Mousterian man from La Chapelle-aux-Saints.[2] The base of the styloid process (*st.*) proves it to have been very small. The petrous portion of the bone exhibits all its characteristic features, with no peculiarity worthy of remark; and the cerebral face of the mastoid bears the usual broad deep groove for the lateral sinus (*si.*). The maximum horizontal extent of the temporal bone is 95 mm., and the greatest depth of its squamous wing above the auditory meatus is 57 mm.; while its maximum thickness at the parieto-mastoid suture is no less than 14 mm.

The various measurements of the parts of the skull already given, and some others that are also of importance, may be conveniently tabulated as below (p. 130), for comparison with the corresponding measurements of the skulls from Gibraltar and La Chapelle-aux-Saints.

The right mandibular ramus (Pl. XX, figs. 2, 2*a*, 2*b*, & 2*c*) is in the same mineralized condition as the skull, and corresponds sufficiently well in size to be referred to the same specimen without any hesitation. It lacks the articular condyle and the upper part of the bone in advance of the molars; but it is otherwise well preserved, and still exhibits the first two molars in their sockets. Its outer face is sufficiently disintegrated to show the direction of the constituent fibres of the bony tissue. The ascending portion, as in the mandibles from Heidelberg and La Chapelle-aux-Saints, is relatively broad, its width just below the sigmoid notch being 45 mm.; while its depth at the coronoid process (*cor.*) is about 70 mm. As in the same jaws, its hinder margin makes an angle of 110° with the inferior margin, its sigmoid notch is comparatively shallow, and the neck of its articular condyle (*cd.*) must have been short. The bone itself is thin, and its outer face is deeply impressed with irregular hollows for

[1] Ann. de Paléont. vol. vi (1911) p. 58.
[2] *Ibid.* pp. 44, 54.

Skull.	*Piltdown.*	*Gibraltar.*	*Neanderthal.*	*La Chapelle.*	*Spy I.*	*Spy II.*	*Australian.*	*Lewes Levels.*
Maximum length	190	190	199	208	200	198	190	182
Maximum width	150	144?	147	156	140	150	126	140
Width at supraorbital ridge	125	...	122	122	114	117	107	110
Width at constriction behind the supraorbital ridge	112	102	107	109	104	106	92	100
Height, basion to vertex	130	...	...	...	...	...	124	143
Do. basion to bregma	130	...	...	131	...	...	125	140
Do. opisthion to vertex	130	...	...	...	...	...	...	
Do. opisthion to bregma	148	...	...	...	...	...	149	155
Do. vertex to glabella-inion line	90	—	80·5	...	81	87	85·5	100
Do. bregma to the same	84	—	76·5	—	69	69·7	70	88
Do. vertex to glabella-lambda line	...	55?	57	...	51	58	56	
Horizontal circumference (by glabella and inion)	540	—	590	600	580	540	518	520
Cephalic index	78 or 79	80?	73·9	75	70	74·80	66·04	76·9
Bregmatic angle	50°	55°?	44°	45·5°	46°	47°	48·30°	
Cranial capacity	1070 c.c.	1080 c.c.	1230 c.c.	1626 c.c.	1500 c.c.	1650 c.c.	1190 c.c.	
Total length of sagittal curve	350 to 360	—	...	357	...	...	...	370
Length of frontal (metopic) curve	120 to 130	—	133	121	105	120?	127	110
Do. of parietal curve	120	—	119	121	118	114	117	150
Do. of occipital curve	110	—	—	115	122	—	...	110
Do. from lambda to inion	55	—	51	...	59	59	...	55
Do. from inion to opisthion	50	...	...	...	...	...	...	49
Nearest approach of temporal fascia to mid-line	36	—	...	65	—	60	29	52
Nearest approach of temporal muscle to mid-line	46	—	...	...	...	...	38	57
Depth of temporal muscle above squamous suture	32	—	...	35	...	...	51	45
Maximum depth of squamous wing above auditory meatus	57	...	...	...	...	...	39	48

Mandible.	*Piltdown.*	*Heidelberg.*	*Spy I.*	*La Chapelle.*
Height of coronoid	70	66·3	60?	60
Width of ascending ramus just below sigmoid notch	45	60	—	45?
Depth at m. 2	27	31·8	33	31?
Do. at symphysis	—	35	38	37
Thickness at m. 2	15	20	14	16
Do. at symphysis	—	17·5	15	16
Length of m. 1	11·5	11·6	10	—
Breadth of m. 1	9·5	11·2	10·5	—
Length of m. 2	12	12·7	10	—
Breadth of m. 2	10	12	10	
Mandibular or goniac angle	110°	110°	—	110°

Note.—Unless otherwise stated, the numerals denote millimetres. Measurements of the fossil skulls cannot be made with great precision, and there are often discrepancies between the results of different authors. For the Gibraltar and Australian skulls the figures are chiefly those of Prof. Sollas; for Neanderthal those of Dr. Schwalbe; for La Chapelle those of Prof. Boule; and for Spy chiefly those of MM. Fraipont and Lohest. Some of the measurements of the Australian skull have been kindly taken by Mr. E. S. Goodrich, F.R.S. The estimates of cranial capacity of the Gibraltar and Spy skulls are those of Prof. A. Keith. The measurements of the Heidelberg mandible are by Dr. O. Schoetensack.

the insertion of a powerful masseter muscle (*ma.*). The horizontal portion, or body of the mandibular ramus, measures only about 27 mm. in depth behind, but must have become a little deeper forwards. External to the first and second molars there is the usual prominent oblique ledge (*b.*) for one of the origins of the buccinator muscle; but this is the only feature visible on the outer face, a large flake of bone behind the position of the mental foramen having been lost when the anterior part was broken. Seen from within, the ascending portion of the ramus is remarkable for the thickening of its anterior margin, to provide a large surface (*t.*) for the insertion of the temporal muscle as far downwards as the alveolar border. A strengthening ridge extends downwards and forwards from the articular condyle to the lower part of the sharply-defined inner edge of the temporal surface. Below and behind this the large dental foramen (*d.*) occurs, though its shape is altered by accidental breaking; and still a little lower there is the slight impress of the mylohyoid groove (*m.g.*). Near the angle (*i.pt.*) might be expected a roughness for the insertion of a powerful internal pterygoid muscle; but the bone bears only slight irregularities and it is very little curved inwards. Farther forward the inner face of the ramus is curiously smooth, the origin of the mylohyoid muscle, which forms so conspicuous a ridge in man, being not marked even by a faint line.

The great width of the temporal insertion, the situation of the mylohyoid groove behind rather than in line with the dental foramen, and the complete absence of the mylohyoid ridge are all characters of the mandible in apes, not in man. It is, therefore, very interesting to note that as the ramus curves round to the symphysis (*s.*) its lower margin exhibits an increasingly wider flattening, which begins beneath the second molar, slopes upwards and outwards, and ends in front in a strongly retreating chin. The inner edge of this flattening is sharply rounded, and at the symphysis itself the inner face of the jaw is so much depressed in its lower part that the bone here has the form of a nearly horizontal plate or flange, closely similar to that found in all the apes. The genio-hyo-glossal and genio-hyoid muscles, in fact, must have had their origin in a deep pit, as in the apes; while the digastric can only have been inserted on the edge of the bony flange, instead of extending far over the lower border as in man. The absence of the upper part of the symphysis in the fossil is therefore particularly unfortunate, and there is ample scope for speculation as to the precise shape of the bony chin and the extent of the anterior part of the alveolar border. The fractured end does not even suffice to determine whether or not the part preserved reaches the middle line; it merely shows that the walls of the jaw are thin, and that the inner tissue must have been coarsely cancellous. As, however, the whole of the bone preserved closely resembles that of a young chimpanzee, it seems reasonable to restore the fossil on this model, and make the slope of the bony chin intermediate between that of the adult ape and that of *Homo heidelbergensis*.

If this restoration prove to be correct, the length of the alveolar border in front of the molars is 60 mm., instead of 30 to 40 mm., as in all known human jaws; and it seems difficult to fill this space without assuming that a relatively large canine was present.

That the canine in any case cannot have been very prominent, seems to be proved by the remarkable flatness of the worn surface of the molar teeth (Pl. XX, fig. 2*c*: *m.* 1, *m.* 2). Enamel and dentine have been equally worn down by very free movements in mastication, and such a marked regular flattening has never been observed among apes, though it is occasionally met with in low types of men. Although the cusps have been worn down to the plane of the central area in each tooth, very little dentine is exposed—much less, in fact, than is seen in the similarly worn teeth of apes. Both the first and second molars are noteworthy for their considerable length in proportion to their width, each being provided behind with a large fifth cusp. They are constricted in the ordinary manner at the base of the crown (figs. 2 & 2*a*, *m.*1, 2), and in each tooth the two divergent roots are completely separate to their upper end. They are thus very different from some human teeth with fused roots which are claimed to be of Palæolithic age.[1] The first molar measures 11·5 mm. in length by 9·5 mm. in width; while the second molar is larger by 0·5 mm. in each direction. The third molar, which is situated almost completely on the inner side of the ascending portion of the jaw, is represented only by its well-preserved socket (fig. 2*c*, *m.* 3), which shows that its two divergent roots resembled those of the other molars in not being fused together. The anterior root must have been wider than the posterior root, and impressed by a vertical median groove along its hinder face. The posterior root is shown to have been the thicker antero-posteriorly. The tooth must have been relatively large, not less than 11 mm. in length, and inclined a little inwards. The molar teeth, therefore, although distinctly human, are of the most primitive type, and must be regarded as reminiscent of the apes in their narrowness. The first molar may be compared with a detached specimen already known from Taubach, in Saxe-Weimar.[2]

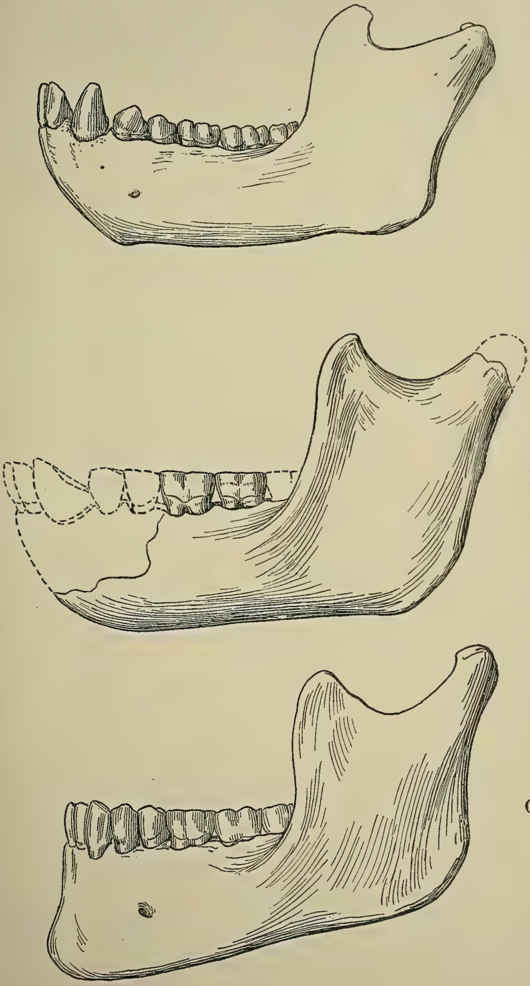
A restored model of the mandible, skilfully made to fit the skull by Mr. Frank O. Barlow, is shown from the left side and from above and below in text-figs. 4–6 (pp. 133–37). It assumes that the actual fossil extends just to the symphysis, and the result is distinctly striking. The jaw is rather wide, but the nearly straight molar-premolar series of the two sides converge only gradually forwards; while both canines and incisors are, of necessity, large and spaced.

While the skull, indeed, is essentially human, only approaching a lower grade in certain characters of the brain (see pp. 145–47), in the attachment for the neck, the extent of the temporal muscles,

[1] *Homo neanderthalensis* var. *krapinensis*, Kramberger, Mitth. Anthrop. Gesellsch. Wien, 1902, p. 191. *Homo breladensis*, Keith & Knowles, Journ. Anat. & Physiol. vol. xlvi (1911) p. 12.

[2] A. Nehring, Zeitschr. für Ethnologie, 1895, p. 338.

Fig. 4.—*Restoration of the Piltdown mandible* (B), *compared with that of man* (C) *and the young chimpanzee* (A), *in left side view; two-thirds of the natural size.*

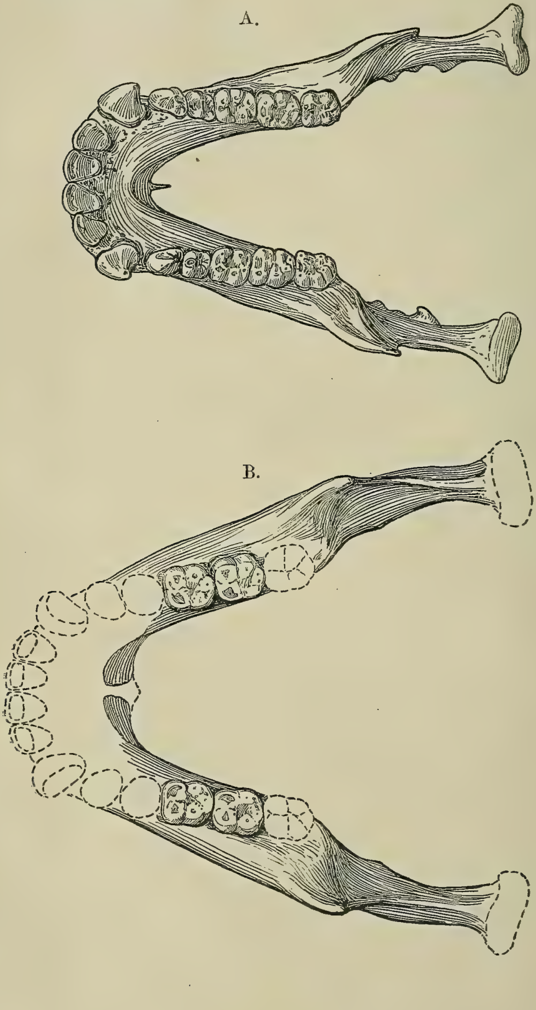


A

B.

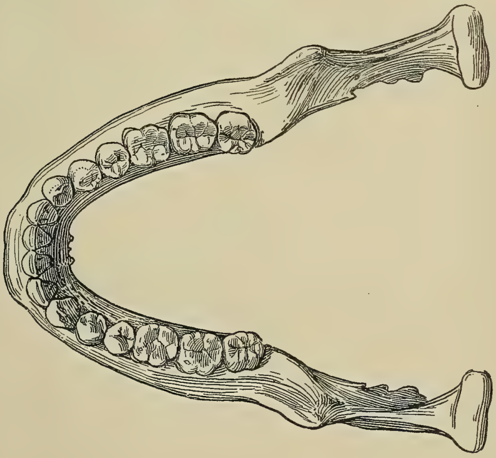
C.

Fig. 5.—*Restoration of the Piltdown mandible* (B), *compared with that of man* (C) *and the chimpanzee* (A), *upper view ; two-thirds of the natural size.*



and in the probably large size of the face, the mandible appears to be almost precisely that of an ape, with nothing human except the molar teeth. Even these approach the ape-pattern in their well-developed fifth cusp and elongated shape. The specimen, therefore, represents an annectant type, and the question arises as to whether it shall be referred to a new species of *Homo* itself, or whether it shall be considered as indicating a hitherto unknown genus. The brain-case alone, though specifically distinguished from all known human crania of equally low brain-capacity, by the characters of its supraorbital border, and the upward extension of its temporal muscles, could scarcely be removed from the genus *Homo*; the bone

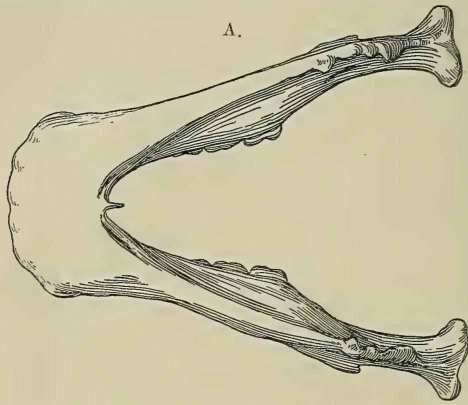
(Fig. 5 *cont.*) C.



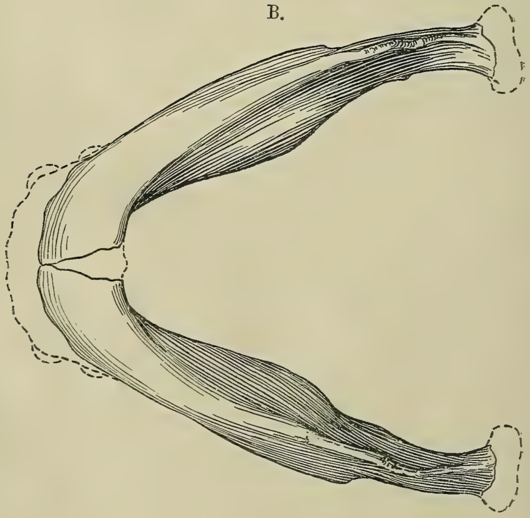
of the mandible so far as preserved, however, is so completely distinct from that of *Homo* in the shape of the symphysis and the parallelism of the molar-premolar series on the two sides, that the facial parts of the skull almost certainly differed in fundamental characters from those of any typically human skull. I therefore propose that the Piltdown specimen be regarded as the type of a new genus of the family Hominidæ, to be named *Eoanthropus* and defined by its ape-like mandibular symphysis, parallel molar-premolar series, and narrow lower molars which do not decrease in size backwards; to which diagnostic characters may probably be added the steep frontal eminence and slight development of

Fig. 6.—*Restoration of the Piltdown mandible* (B), *compared with that of man* (C) *and the chimpanzee* (A), *lower view; two-thirds of the natural size.*

A.



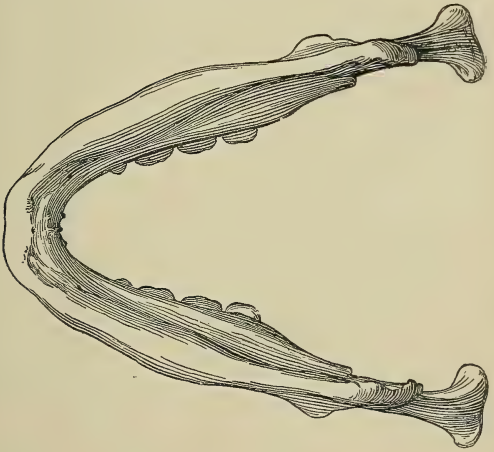
B.



brow-ridges. The species of which the skull and mandible have now been described in detail may be named *Eoanthropus dawsoni*, in honour of its discoverer.

The differences between the mandible of *E. dawsoni* and other primitive human mandibles hitherto discovered are very remarkable; but they are especially striking when comparison is made between the new specimen and the mandible of *Homo heidelbergensis* (fig. 7, p. 138).[1] These two jaws can be very satisfactorily compared: because the first and second molars are almost identical in length in the two specimens, and their outline may be exactly superposed, as shown in fig. 7. While separated by the characters of the inner face and symphysis already noted (p. 131), the mandible of *Eoanthropus dawsoni* is thus seen to differ also in its comparative slenderness and its regular deepening to the symphysial end; and, whereas the anterior teeth of the new specimen must have occupied a space of about 60 mm., those of *Homo heidelbergensis* have only the usual extreme human extent of 40 mm. When it is remembered that *Eoanthropus dawsoni* and *H. heidelbergensis* are almost (if not absolutely) of the same geological age, we are thus led to the interesting conclusion that at

(Fig. 6 *cont.*) C.

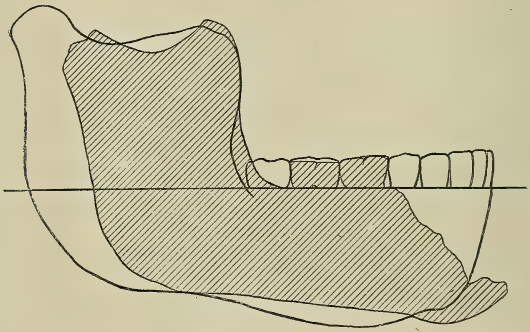


[1] O. Schoetensack, 'Der Unterkiefer des *Homo heidelbergensis*' Leipzig, 1908.

the end of the Pliocene Epoch the representatives of man in Western Europe were already differentiated into widely divergent groups.

The skull is equally remarkable when compared with the other undoubtedly ancient human skulls hitherto known, and suggests generalizations of even wider import. The discoveries of the brain-case of *Pithecanthropus* and several skulls of the Mousterian (Neanderthal) type have led to the very general belief that early man was characterized by a low, flattened forehead and a prominent bony brow, like the corresponding parts in the adult existing apes. The only opinions to the contrary have been based on discoveries of very doubtful authenticity, or on theoretical considerations which still need to be tested by more facts. Now, the Piltdown specimen, which is certainly the oldest typically-human brain-case

Fig. 7.—*Mandibular ramus from Piltdown superposed on that of* Homo heidelbergensis; *two-thirds of the natural size.*



hitherto found, exhibits no anterior flattening, but has the frontal eminence as steep as in modern man, without any prominent supraorbital ridge. The small development of this ridge may possibly be due in some degree to the circumstance that the new specimen represents a female, as suggested by the small backward extent of the temporal muscles, the weakness of the mandible, and the relatively small size of the mastoid processes. Even so, however, a full-grown male of the same race could not have developed a supraorbital prominence approaching that of Mousterian man. The conclusion seems therefore inevitable, that at least one type of man with a high forehead was already in existence in Western Europe long before Mousterian man, with a low and prominent brow, spread widely in this region. It is also clear that this earlier man had a much lower cranial capacity than most examples of the later low-browed man. We are thus reminded of the interesting fact

that, during the post-natal life of all the existing apes, the skull has at first the curiously rounded shape of the Piltdown specimen, with a high frontal eminence and scarcely any brow-ridge; while as growth proceeds a postorbital constriction begins, the bony brow grows forwards, the forehead becomes flattened, and the familiar well-marked ape-skull is the result (fig. 8, p. 140). Our knowledge of the principles of palæontology compels us to suppose that the full-grown skull in the ancestral mid-Tertiary apes was of the immature rounded shape just mentioned, although we have not yet been fortunate enough to discover an example; and, during the lapse of Upper Tertiary time, the skull-type in the whole race of apes has gradually undergone changes which are more or less exactly recapitulated in the life-history of each individual recent ape. Hence, it seems reasonable to interpret the Piltdown skull as exhibiting a closer resemblance to the skulls of the truly ancestral mid-Tertiary apes than any fossil human skull hitherto found. If this view be accepted, the Piltdown type (fig. 9, p. 141) has gradually become modified into the later Mousterian type (fig. 10, p. 141) by a series of changes similar to those passed through by the early apes as they evolved into the typical modern apes, and corresponding with the stages in the development of the skull in an existing ape-individual. It tends to support the theory that Mousterian man was a degenerate offshoot of early man, and probably became extinct; while surviving man may have arisen directly from the primitive source of which the Piltdown skull provides the first discovered evidence.

For much valuable help in studying these human remains I wish especially to thank Mr. W. P. Pycraft, A.L.S., and Mr. Arthur S. Underwood, M.R.C.S.

The Associated Mammalia.

The associated mammalian remains are well mineralized with oxide of iron, and, as might be expected in so coarse a gravel, they are all very fragmentary.

Mastodon (Pl. XXI, figs. 1, 1 *a*, & 1 *b*).—A much-rolled specimen is readily identified as the cusp of a molar of *Mastodon*, of the same type as *M. arvernensis*. The outer enamel, with the characteristic irregularities, is well preserved, and the waterworn base shows the upper end of the large pulp-cavity. The cusp has three apices closely pressed together, the median one being relatively small and crushed between the others; and the fossil is sufficiently complete to show that it was an isolated eminence on a tooth, not part of a continuous ridge.

Stegodon (Pl. XXI, figs. 2, 2 *a*, 3, & 3 *a*).—Two fragments of a large Proboscidean molar, which have evidently been broken with great force but are scarcely rolled, are referable to a very primitive type of true elephant. One piece (figs. 2 & 2 *a*), in which the

Fig. 8.—*Outlines (left lateral view) of the skull and mandible of the young and adult chimpanzee; half of the natural size.*

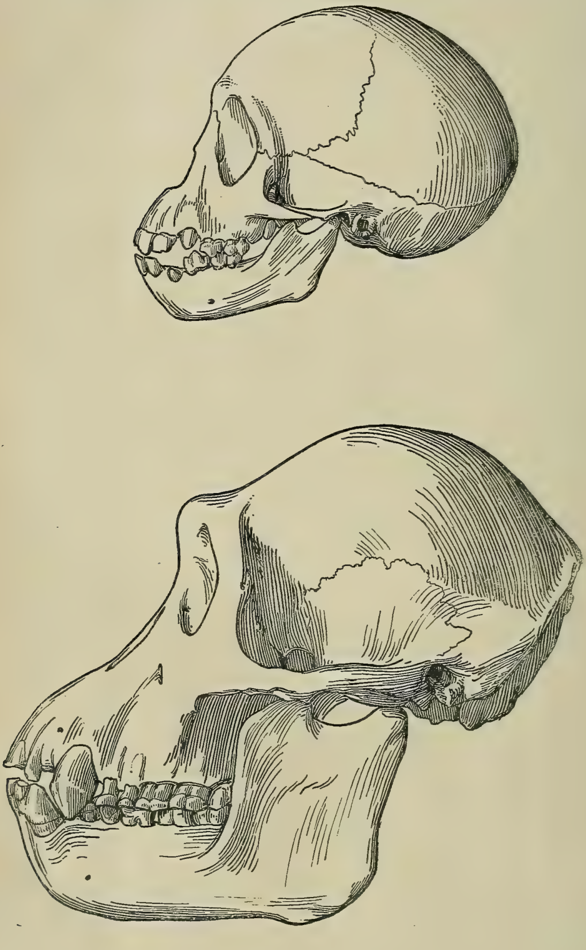


Fig. 9.—*Outline (left lateral view) of the skull and mandible of* Eoanthropus dawsoni, *with the bones of the face and the symphysis of the mandible in dotted outline.* ($\frac{1}{3}$ *nat. size.*)

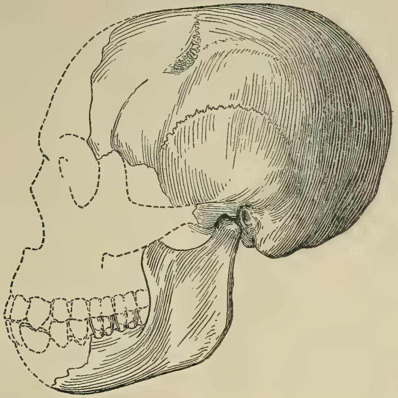
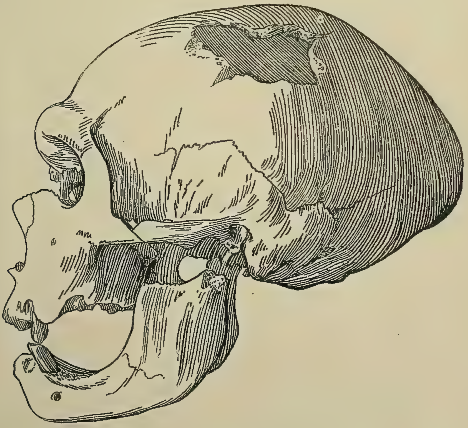


Fig. 10.—*Outline (left lateral view) of the human skull and mandible from La Chapelle-aux-Saints, after M. Boule.* ($\frac{1}{3}$ *nat. size.*)



ridges are subdivided into round digitations, seems to belong to the hinder part of a molar just coming into wear; while the smaller piece (figs. 3 & 3 *a*), perhaps of the same tooth, represents the much-worn middle or anterior portion, with the enamel very wavy in section. Both specimens fortunately exhibit a complete valley in cross-section (figs. 2 *a* & 3 *a*), and so allow the angle of divergence of the ridges to be determined. In the hinder fragment this angle measures about 20°, in the other a little more; and in each case the walls of the valley are divergent to the summit, not parallel in the upper part. The valleys are thus very wide in proportion to their depth, and the tooth evidently belongs to that primitive section of the genus *Elephas* to which Falconer gave the name of *Stegodon*.[1] It cannot be referred to the Upper Pliocene *Elephas meridionalis*, because in this species the valleys are deeper in proportion to their width, while the ridges are more plate-like and parallel in their upper portion. The new specimen is, therefore, of an earlier Pliocene type, which is best known from the Siwalik Formation in India, and has not hitherto been found in Western Europe.[2]

Hippopotamus (Pl. XXI, figs. 4, 5, & 5 *a*).—The broken middle portion of a left lower molar (probably m. 3) of *Hippopotamus* (fig. 4) agrees well in size and pattern with many of the corresponding teeth of the ordinary *H. amphibius*, and may probably be referred to this species. It is only peculiar in exhibiting a small tubercle in the valley on the outer side—an addition which occasionally occurs in more than one species. There is also an example of the first lower premolar (figs. 5 & 5 *a*), with the usual undivided root. Its crown bears the characteristic fine rugosity, with a trace of the cingulum at the base. Both these teeth are much worn by mastication, and they may have belonged to the same individual.

Cervus elaphus (Pl. XXI, figs. 6 & 6 *a*).—The base of a large left antler of the common red deer is remarkable for its smoothness, only slight traces of the usual longitudinal furrowing being visible near the burr, which is coarse and prominent. The bone is flattened antero-posteriorly, the hinder face being especially flat, and the plane curving forwards at the origin of the lower brow-tyne. On its anterior face (fig. 6) a rounded longitudinal ridge rises near the outer margin upwards to a thickening at the origin of the upper brow-tyne. The diameter of the base of the beam within the burr is about 70 mm., and the height to the origin of the second brow-tyne is 120 mm.

The collection also includes the proximal end of a metatarsal of *Cervus* split longitudinally (see p. 121).

1 Q. J. G. S. vol. xxi (1865) p. 258.

2 A form of Proboscidean tooth nearly as primitive as that from Piltdown has been recorded from the Pliocene of Lower Austria; see G. Schlesinger, Monatsbl. Verein. Landeskund. Niederösterr. 1911, No. 16.

Equus.—A first or second left upper molar of an aged horse cannot be specifically determined. The tooth is as broad as long, its enamel is scarcely crimped, and the extent of its inner column is slightly less than half of the antero-posterior measurement of the tooth.

Castor fiber (Pl. XXI, figs. 7, 7 *a*, & 8).—A lower molar and a lower fourth premolar of a beaver, referable to the genus *Castor*, agree exactly with the corresponding teeth of the Pleistocene and existing species, *C. fiber*. They exhibit no plication of the enamel such as occurs in the Upper Pliocene *C. plicidens*.[1]

Of these mammalian remains, the fragment of tooth of *Mastodon* is so much more waterworn than the others that it may be regarded without hesitation as having been derived from some older deposit. The broken pieces of *Stegodon* must also have been extremely battered by transport, if their fracture is really natural and not due to the carelessness of workmen. It seems likely, therefore, that these typically Pliocene fossils are of earlier date than the deposition of the Piltdown gravel. The teeth of *Hippopotamus*, however, may be either Upper Pliocene or Pleistocene in age; while the teeth of *Castor* are most probably Pleistocene, and typical specimens of *Cervus elaphus* have never hitherto been found below the Pleistocene. Although, therefore, the mammalian remains do not determine the age of the gravel with certainty, they tend to assign it to the Pleistocene Epoch; and, when it is remembered that (as pointed out by Mr. Dawson, p. 123) most of the contained 'Eoliths' are waterworn, while the associated rude Palæolithic implements have sharp edges, it seems more reasonable to date the deposit by the latter than by the former. If, as the result of these considerations, the gravel proves to have been formed in an early part of the Pleistocene Epoch, the age of the human remains is also decided: for they are very little waterworn, and the skull and mandible would not have occurred in close association if they had been transported far from the spot at which they were originally entombed.

EXPLANATION OF PLATES XVIII–XXI.

Plate XVIII.

Eoanthropus dawsoni, gen. et sp. nov.; from a gravel near Piltdown Common, Fletching (Sussex).

Fig. 1. Restored model of skull, upper view.
2. Do. do. do. front view.
3. Do. do. do. left side view.
4. Do. do. do. back view.

[All the figures are of half the natural size, and the darkly-shaded parts indicate the pieces of bone actually preserved.]

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[1] C. I. Forsyth-Major, Proc. Zool. Soc. 1908, pp. 630–31, text-fig. 132.

Plate XIX.

Eoanthropus dawsoni, gen. et sp. nov.; from a gravel near Piltdown Common, Fletching (Sussex).

Fig. 1. Left frontal in outer side view; (1 *a*) front view and (1 *b*) lower view of the lateral portion.

cer. = cerebral surface; *cor.* = coronal suture; *e.a.p.* = external angular process; *m.f.*=facette for malar; *orb.*=roof of orbit; *s.*=broken section of frontal bone; *s.f.*=facette for sphenoid; *t.*=temporal ridge.

2. Left temporal, lacking the upper part of the squamous wing, in outer view; (2 *a*) lower view, (2 *b*) inner view, and (2 *c*) upper view.

car.=openings of carotid canal, the lower blocked by a pebble; *e.a.m.*=external auditory meatus, blocked by a pebble; *gl.*=glenoid fossa; *i.a.m.*=internal auditory meatus; *mal.*=process for malar; *mast.*=mastoid process; *o.f.*= suture for occipital; *p.a.p.*=post-articular process; *p.f.*=suture for parietal; *s.f.*=suture for sphenoid; *si.*=broad groove for lateral sinus; *st.*=base of styloid process.

[All the figures are of the natural size.]

Plate XX.

Eoanthropus dawsoni, gen. et sp. nov.; from a gravel near Piltdown Common, Fletching (Sussex).

Fig. 1. Imperfect occipital in outer view; (1 *a*) inner view and (1 *b*) broken vertical section, left side.

cb.=cerebellar fossa; *cer.*=cerebral fossa; *e.o.c.*=external occipital crest; *e.o.p.*=external occipital protuberance; *f.mag.*=foramen magnum; *i.o.c.*=internal occipital crest; *lamb.*=portion of lambdoid suture; *l.c.l.*=lower curved line; *l.s.*=linea suprema; *si.*= groove for lateral sinus; *u.c.l.*=upper curved line.

2. Right mandibular ramus, imperfect at the symphysis, in outer view; (2 *a*) inner view, (2 *b*) lower view, and (2 *c*) upper view.

b.=ridge below origin of buccinator muscle; *cd.*=neck of condyle; *cor.*=coronoid process; *d.*=inferior dental foramen; *i.pt.*=area of insertion of internal pterygoid muscle; *m.* 1, *m.* 2=first and second molars; *m.* 3 = socket for third molar; *m.g.* = mylohyoid groove; *ma.*=area of insertion of masseter muscle; *s.*=incurved bony flange of symphysis; *t.*=area of insertion of temporal muscle.

[All the figures are of the natural size.]

Plate XXI.

Mammalian remains found with *Eoanthropus dawsoni*, in a gravel near Piltdown Common, Fletching (Sussex).

Fig. 1. *Mastodon* sp.: waterworn cusp of molar tooth, side view; (1 *a*) front view and (1 *b*) back view. (See p. 139.)

2. *Stegodon* sp.: hinder fragment of molar tooth, crown view; and (2 *a*) vertical longitudinal section. (See p. 139.)

3. *Stegodon* sp.: fragment of molar tooth worn by mastication, crown view; and (3 *a*) vertical longitudinal section. (See p. 142.)

4. *Hippopotamus* sp.: crown view of portion of lower molar tooth. (See p. 142.)

5. *Hippopotamus* sp.: lower first premolar, outer view; and (5 *a*) end view.

6. *Cervus elaphus* Linn.: basal fragment of left antler, front view; and (6 *a*) outer view, three-quarters of the natural size. (See p. 142.)

7. *Castor fiber*: first or second right lower molar, crown view; and (7 *a*) outer view. (See p. 143.)

8. *Castor fiber*: right lower fourth premolar, crown view.

[All the figures are of the natural size, except figs. 6 & 6*a*.]

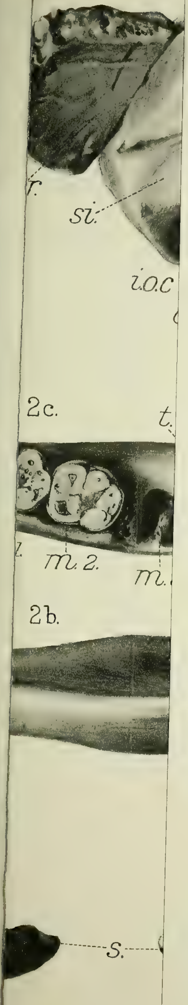
1b.

OPUS DAW

G. M Woodward, del.

Bemrose, Collo, Derby

EOANTHROPUS DAWSONI.



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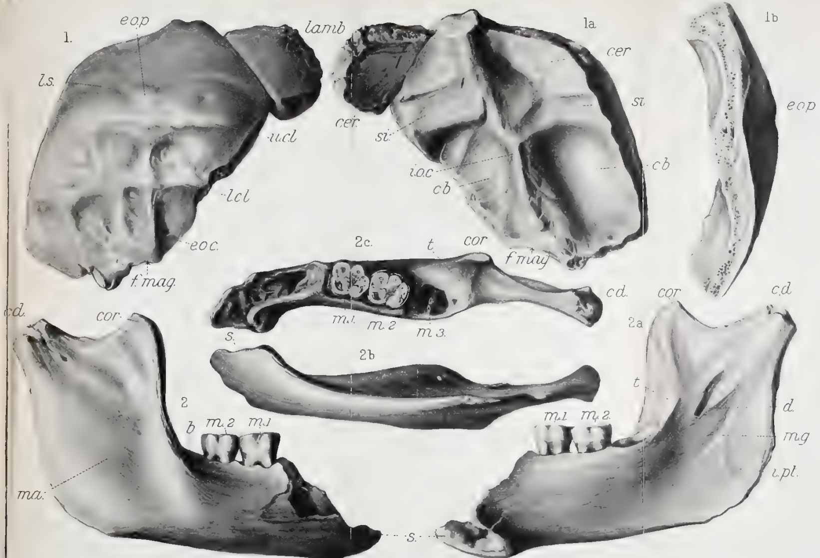

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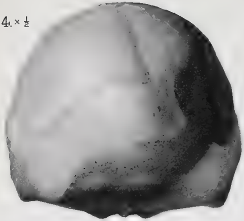
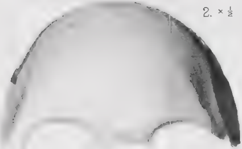
EOANTHROPUS DAWSONI.

ROPUS DA

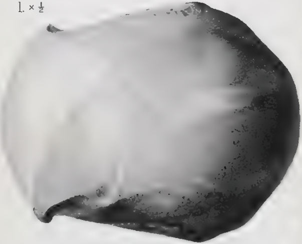
4. × ½



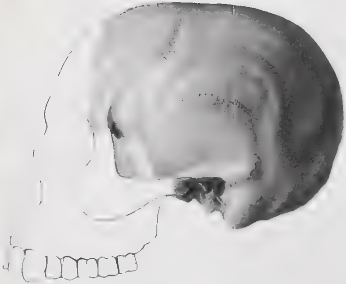
2. × ½



1. × ½



3. × ½



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Bemrose, Collo, Derby

EOANTHROPUS DAWSONI.

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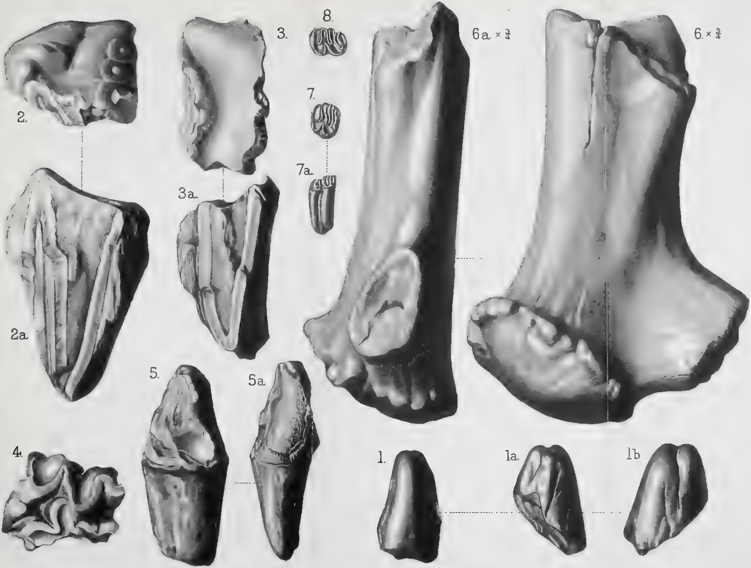

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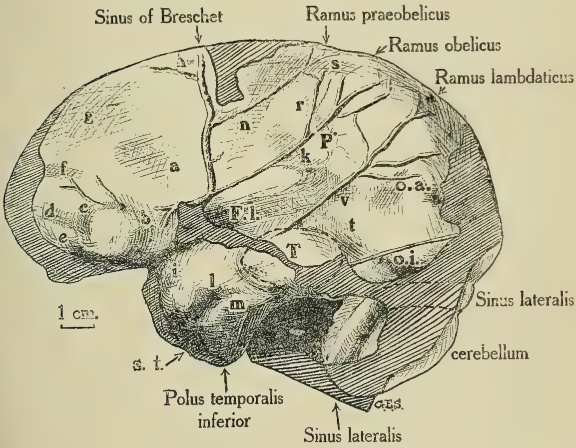
MAMMALIAN REMAINS found with EOANTHROPUS DAWSONI.

APPENDIX. — PRELIMINARY REPORT *on the* CRANIAL CAST. By GRAFTON ELLIOT SMITH, M.A., M.D., F.R.S., Professor of Anatomy in the Victoria University of Manchester.

THE observations recorded in these notes were made upon the cranial cast which was submitted to me for examination by Dr. Smith Woodward, under whose direction the remains of the cranium were fitted together and the cast obtained from it.

The accompanying sketch (fig. 11) represents the left norma

Fig. 11.—*Left norma lateralis of the internal cast of the skull from Piltdown.*



lateralis, and will explain better than a description the extent of missing cranial wall. The greater part of the right parietal bone and a considerable part of the occipital were found, and it was possible to fit them into position. Thus the form and proportions of the whole brain can be estimated.

The sharply-cut meningeal grooves upon the bones have produced upon the cast the whole pattern of the middle meningeal veins and arteries with great distinctness. The diagram shows the arrangement upon the left side: upon the right it conforms to Giuffrida-Ruggeri's Typus 1.[1]

Unfortunately, there are only very slight indications of the

[1] 'Ueber die endocranischen Furchen der *Arteria meningea media* beim Menschen' Zeitschr. f. Morph. & Anthropol. vol. xv (1912) p. 403.

arrangement of the furrows upon the surface of the cerebral hemisphere. Nevertheless many of them can be detected, if not by sight, by passing the finger over the surface and locating the depressions by touch. These features are represented (with considerable exaggeration so far as depth of shading is concerned) in the diagram (fig. 11) on the preceding page.

At first sight, the brain presents a considerable resemblance to the well-known Palæolithic brain-casts, and especially to those obtained from the Gibraltar and La Quina remains, which are supposed to be women's. Like these casts this one is relatively long, narrow, and especially flat; but it is smaller, and presents more primitive features than any known human brain or cranial cast.

The position and relations of the cerebellum present a marked contrast with those exhibited in the La Chapelle-aux-Saints, La Quina, and Gibraltar casts; the frontal and parietal regions are less expanded, and the temporal region exhibits some important and very significant differences.

The length of the left cerebral hemisphere (which was probably a little longer than the right, because the left occipital pole was the more prominent, a condition found in the brains of modern right-handed men)[1] is 163 mm. The breadth in the frontal region (just below the point marked *a*) is 101 mm.: the maximum breadth of the hemispheres is at the point T, low down on the temporal area, and measures 130 mm.; but at the point P in the parietal region, corresponding to the place where anthropometrists measure the breadth of the skull, the breadth of the brain-cast is only 102 mm. The maximum height, measured from the [restored] tip of the curiously pendent temporal region (designated 'Polus temporalis inferior,' to distinguish it from the temporal pole of the modern man's brain), is 106 mm.; but farther back (opposite T) the height sinks to 86 mm.

In this note I do not propose to discuss the significance of the faint glimmerings which this cast affords of the pattern of the convolutions, except to remark that there are indications sufficiently definite to enable us to plot out a great part of the singularly primitive arrangement of sulci.

I have already referred to the diminution and flattening of the frontal and parietal regions. In the centre of the latter there is an area, which is well circumscribed by recognizable sulci (*s*, *n*, *k*, *v*, and *oa*), raised up into a low hillock, the summit of which is at the point marked P. It is more pronounced on the right hemisphere. This indication of the expansion of an area, the large dimensions and fulness of which are especially characteristic of the human brain, is peculiarly significant, when taken in conjunction with a similar condition in the temporal region.

One of the most striking features of this brain-cast is the deep

[1] 'On the Asymmetry of the Caudal Poles of the Cerebral Hemispheres & its Relation to the Occipital Bone' Anat. Anzeiger, vol. xxx (1907) p. 574.

excavation of the temporal area, to form the wide bay between the inferior temporal pole and the cerebellum. This is due to the marked attenuation of the temporal region; but, as we have already seen in the case of the parietal region, so also here are definite signs that the expansion has begun which eventually will transform this area into the very different configuration that it presents in the modern brain. There is a very prominent elliptical swelling, the summit of which (at T) is raised more than a centimetre above the level of the surrounding cortex. It is 2 centimetres in vertical measurement and almost 3 centimetres long. This peculiar conformation assumes quite a special interest when it is remembered that this obviously expanding area occupies the position where in the modern human brain is developed the territory which recent clinical research leads us to associate with the power of 'spontaneous elaboration of speech and the ability to recall names' (Adolf Meyer).

The configuration of the anterior part of the temporal area is also peculiar, though a suggestion of the same kind of form is seen in the Gibraltar brain-cast. Below the point marked *l* the surface slopes inwards towards the mesial plane, so that the fulness of the temporal pole of the modern brain is wanting.

There is marked asymmetry of the cerebellum and of the occipital poles of the cerebrum.

Taking all its features into consideration, we must regard this as being the most primitive and most simian human brain so far recorded; one, moreover, such as might reasonably have been expected to be associated in one and the same individual with the mandible which so definitely indicates the zoological rank of its original possessor.

The apparent paradox of the association of a simian jaw with a human brain is not surprising to anyone familiar with recent research upon the evolution of man. In the process of evolving the brain of man from the ape the superficial area of the cerebral cortex must necessarily be tripled; and this expansion was not like the mere growth of a muscle with exercise, but the gradual building-up of the most complex mechanism in existence. The growth of the brain preceded the refinement of the features and of the somatic characters in general.

Discussion.

Sir Ray Lankester congratulated the Authors on the very clear and interesting account given by them of their important discovery. Two distinct questions arose in regard to the bones discovered: first, what are the characters of skull and jaw indicated, and, secondly, what is the geological age of the specimens? He had been allowed to examine the jaw and skull some weeks ago, and with Mr. Dawson had visited the locality where they were found. In regard to the zoological characters of the individual indicated by the bones—everything depended on the little projecting piece at the

broken front end of the mandible, proving the existence of a long and flattened symphysis as in the chimpanzee. He considered that Dr. Smith Woodward was fully justified in the conclusion which he drew from this portion of the specimen as to the ape-like character of the completed jaw and of its dentition; and, though the restoration of the jaw on this basis undertaken by Dr. Smith Woodward was a very bold step, he considered that it was justified. He considered that this lower jaw presents simian characters distinct from, and more decisive than, those of the Heidelberg jaw. As to the age of the specimens, he did not think that any conclusion could be arrived at; for the human bones might be earlier than the flints and as early as the *Mastodon* tooth, or later than either. He did not consider it certain that the lower jaw and the skull belonged to the same individual; and hence no convincing argument as to their age could be drawn from their juxtaposition in the gravel. He would prefer not to use the word 'Eolith' to describe any flint-implement, or supposed flint-implement. Those called 'Eoliths' by Mr. Dawson resembled (as did many pieces of the flint) the flints of the High Plateau-gravel of Ightham. The coarsely-worked triangular and irregular flints found in the gravel were certainly of a different character, and probably later. But he did not agree to their being termed 'Chellean' or 'early Chellean.' Chelles was simply a locality, and there was no definite 'form' of flint-implement which had been designated by the word 'Chellean.' It was better to describe the forms of flint-implements, without making use of names for them which had no authorized and accepted meaning and might lead to misunderstanding.

Prof. A. Keith regarded the discovery of fossil human remains just announced as by far the most important ever made in England, and of equal, if not of greater consequence than any other discovery yet made, either at home or abroad. He agreed that the reconstruction of the skull had been executed with great skill, the only point in the restoration about which he was not convinced being the chin-region of the mandible and the form of the incisor, canine, and premolar teeth. The restoration approached too nearly the characters of the chimpanzee. The very simian characters of the sub-symphysial region of the mandible, the undoubtedly large anterior teeth, the primitive characters of the skull and brain, seemed to him altogether incompatible with the Chellean age assigned by the Authors. In his opinion the skull must be assigned to the same age as the mammalian remains, which were admittedly Pliocene. In the speaker's opinion, Tertiary man had thus been discovered in Sussex. In coming to this conclusion the speaker was influenced by the fact that in the Heidelberg jaw, which was of early Pleistocene date, the symphysial region of the jaw was essentially human in its markings and characters; whereas the same features in the remains just described were simian, and therefore presumably much earlier.

Prof. Boyd Dawkins said that he agreed with the Authors of the paper that the deposit containing the human remains belonged

to the Pleistocene age, and that the Pliocene mammalia in it—*Mastodon arvernensis* and the rest—had been derived from a Pliocene stratum formerly existing in that area. The latter were merely adventitious, and were no proof of the Pliocene age of the stratum. The Palæolithic implements were, in his belief, of the same age as the human bones. There was no connexion between the faculty of speech and the capacity for making implements, as was urged by the last speaker. The evidence was clear that this discovery revealed a missing link between man and the higher apes, appearing at that stage of the evolution of the higher mammalia in which it may be looked for—in the Pleistocene age. The modern type of man had no place in this age.

He congratulated the Society on having had the clear and lucid statement of the Authors supplemented by the valuable remarks of Prof. Elliot Smith, the highest authority on the human brain.

Dr. Duckworth agreed entirely with the Authors as to the importance of the Piltdown skull, and also as to its general significance. It was justifiable to associate the various fragments as parts of one human skull; and the simultaneous presence of so many simian characters in one and the same specimen was a point of great significance. Almost any one of those characters might be detected singly in human crania of existing types, especially if search were directed to the more lowly of those. Even the mylohyoid ridge was not so constant as Dr. Smith Woodward suggested. But, so far, the search made by the speaker for a flange-like conformation in a human jaw had been quite unsuccessful. This character, even alone, possessed accordingly the great importance attributed to it by Dr. Smith Woodward. On the anatomical side, the Piltdown skull realized largely the anticipations of students of human evolution. To fulfil those anticipations completely, the problem of the precise antiquity of the skull required solution. Anatomists would, therefore, await eagerly the conclusions formed by geologists on this aspect of the subject.

Mr. Clement Reid observed that no detailed 'drift survey' had yet been made of this particular area, but perhaps the survey of the Sussex coastal plain might throw light on the age of the deposit at Piltdown. In the coastal plain the Pleistocene deposits fall into three main groups. At the bottom is the erratic deposit of Selsey, probably contemporaneous with the Chalky Boulder Clay. Above comes a series of interglacial deposits showing varying climates and varying amounts of submergence, the submergence culminating in the Goodwood raised beach, at 135 feet above the sea, and passing away in the lesser submergence shown by the raised beach of Brighton. Above all these marine and fluviomarine deposits lies the great sheet of Coombe Rock, which shows a recurrence of Arctic conditions, perhaps dry cold. The uppermost Pleistocene deposit is probably of Mousterian date.

The speaker tried to trace these deposits of the coastal plain continuously, through the valleys which breach the South Downs, into the Wealden area, but without much success. It seemed,

however, that the low plateau of the Weald, on which the Piltdown deposit probably lies, must belong to a period later than that of maximum depression, for otherwise these lowlands of the Weald would be covered by marine deposits, as is the coastal plain. It was impossible to speak with confidence, but the whole of the evidence suggested that the Piltdown deposit and the plateau on which it rests belong to a base-level plain, which originated about the period of the Brighton raised beach. The deposits are not pre-Glacial or even early Pleistocene—they belong to an epoch long after the first cold period had passed away; but they occur at the very base of the great implement-bearing succession of Palæolithic deposits in the South-East of England.

Prof. WATERSTON pointed out that, if the reconstruction of the cranium and mandible were accepted, it was quite clear that the former was human in practically all its essential characters; while the latter with equal clearness resembled, in all its details, the mandible of the chimpanzee. It was, therefore, very difficult to believe that the two specimens could have come from the same individual. One of the temporal bones, including the glenoid fossa, was complete, and Dr. Smith Woodward had pointed out how closely this bone and the fossa resembled the corresponding parts in modern man. It must be borne in mind that the configuration of the glenoid fossæ in man was such as to adapt them for articulation with a human jaw, and not with the mandible as found in the chimpanzee; and, if the jaw had formed part of the skull, it was precisely in the temporal bone that one would have anticipated some variation in structure from the present-day condition.

Mr. A. S. KENNARD was of opinion that the gravel-spread in which the remains were found should be correlated with the High Terrace of the Lower Thames Valley: the height above the present stream-level was practically the same, and the flint-implements were identical. With regard to the Pliocene age of some of the fossils from Sussex, it must be remembered that the High Terrace of the Thames has yielded several characteristic Pliocene forms. The true succession of the Pleistocene had yet to be worked out, and it must be based on palæontological evidence.

Mr. REGINALD SMITH remarked that the flint-implements recovered were of mixed character, and the only course was to date the gravel by the latest specimen. Those exhibited were of the Chelles stage, if not earlier; and, to judge from the photographs shown on the screen, there were hand-axes of the St. Acheul stage in an unrolled condition. While it required a developed brain to manufacture such implements, it was surprising to find so simian a jaw in the later part of the river-gravel period, and the dilemma still remained. It was a misfortune that the Geological Survey had not visited that area of the Weald in recent years, as it would be interesting to know the relation of the present deposit to the Limpsfield gravel with its homogeneous and well-made implements,

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[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

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Vol. LXIX.
PART 2.

JUNE 1913.

No. 274.

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

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SESSION 1913–1914.

1913.

Wednesday,	November	5*—19*
,,	December	3 —17*

1914.

Wednesday,	January	7*—21*
,,	February (*Anniversary*, Friday, Feb. 20th)......	4*—25*
,,	March.........................	11 —25*
,,	April	8 —29*
,,	May	13 —27*
,,	June	10 —24*

[*Business will commence at Eight o'Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

which would one day be dated with precision. Successive discoveries justified the adoption of the French classification; and it was idle to decry or ignore the types and terminology that made European archæologists mutually intelligible, and in fact constituted the grammar of prehistory.

Mr. E. T. Newton called attention to the highly-mineralized condition of the specimens, which seemed to point to their being of Pliocene rather than of Pleistocene age.

The President (Dr. A. Strahan) regretted that, owing to the lateness of the hour, it had become necessary to close this interesting discussion, and called upon the Authors to reply to the points that had been raised.

Mr. Dawson thanked the Fellows for their kind reception of his paper and for their interesting discussion.

He was quite prepared, from an anthropological point of view, to accept an earlier date for the origin of the human remains, and Dr. Woodward and he had perhaps erred on the side of caution in placing the date as early Pleistocene. However, the stratigraphical aspect of the occurrence, as at present understood, compelled them to suggest the comparatively later date for the human remains.

The occurrence of certain Pliocene specimens in a considerably rolled condition, while the human remains bore little traces of rolling, suggested a difference as to age, but not to the extent of excluding the possibility of their being coeval. The rolled specimens might have entered the stream farther up the river than the human remains, and thus might have drifted into the hole or pocket, in the river-bed, where they were found, during the same age but in different condition. Then, again, the skull might have been surrounded by some colloid material which preserved it in its passage from some earlier deposit. It must be admitted that any attempt to fix an exact geological date for specimens found in a gravel-bed is fraught with difficulties.

He expressed his thanks to Mr. S. A. Woodhead for his analyses; to Dr. Edgar Willett for kind assistance in tracing the gravel; and to Mr. Ruskin Butterfield and Mr. A. W. Pigott for the loan of implements found at Fairlight.

In conclusion, Mr. Dawson expressed his intention of offering the specimens as a gift to the Trustees of the British Museum.

Dr. Smith Woodward admitted that the restoration of the symphysial end of the mandible exhibited was a bold experiment, but he failed at present to conceive of any other interpretation of the fossil. Remembering the failure of Mrs. Selenka's great excavations in Java where *Pithecanthropus* was discovered, he did not anticipate certain success in future work at Piltdown, but he hoped to take part in further diggings. He did not think that the differences between the Heidelberg and the Piltdown mandibles necessarily implied differences of geological age. The swamps and forests of the Weald in early Pleistocene times may have been a refuge for a backward race.

9. *The* 'Kelloway Rock' *of* Scarborough.[1]

By S. S. Buckman, F.G.S. (Read March 5th, 1913.)

Contents.

I. The Rock and its Ammonite Fauna.

Over fifty years ago an important paper on 'The Kelloway Rock of the Yorkshire Coast' was published by John Leckenby in this Society's Journal.[2] It dealt chiefly, if not entirely, with the development of the stratum in the neighbourhood of Scarborough. From this rock he recorded over thirty species of ammonites, many of which were new. Several of these were not figured, and they may be said to have remained almost unknown to science, except perhaps locally. Even of those figured it has been difficult to determine from the descriptions and illustrations what were their generic affinities—a task not altogether easy, even when the specimens themselves are handled.

It is obvious from the ammonite fauna which Leckenby described that the Kelloway Rock of Yorkshire comprises more than the Kellaways Rock of Wiltshire, that it is in part a calcareous equivalent of the Oxford Clay of the southern counties. But, at the same time, this does not state the whole of the facts: for the ammonite fauna of the Yorkshire stratum is not found, so far as many species are concerned, in the Oxford Clay of the southern counties; while certain species of the Kellaways Rock are absent from the Yorkshire deposit. It therefore becomes of interest to see what the ammonites are, and what zonal series they represent.

By the kindness of Prof. McKenny Hughes and Mr. Woods of the Sedgwick Museum, Cambridge, all the types of the ammonites described by Leckenby which are in their possession have been sent to me for study.[3] The authorities of the Museum of Practical Geology, Jermyn Street, London, have also sent to me a considerable series of Callovian-Oxfordian ammonites for determination, among them being many species from the Kelloway Rock of Yorkshire. To all these gentlemen I beg to tender my best thanks.

[1] The appellation 'Kelloway' is here used for quotations from Leckenby or in reference to Yorkshire beds, and 'Kellaways' in relation to deposits in Wiltshire and elsewhere.

[2] Q. J. G. S. vol. xv (1859) p. 4.

[3] The intention is to figure these types in some future issues of 'Yorkshire Type Ammonites.'

From the examination of these specimens it is possible (1) to say what the ammonite fauna is; (2) to arrange the ammonites in groups, according to the different matrices which they exhibit: and (3) to make a supposition as to the relative order of the different matrices. The results arrived at may be stated as follows, beginning with the bed which underlies the so-called 'Oxford Clay' of Yorkshire, according to the statements in the literature.

TABLE I.—MATRICES AND AMMONITE FAUNA OF THE 'KELLOWAY ROCK' OF SCARBOROUGH.

GREGARIUM ZONE.

Bluish, calcareous, with many close-packed oolitic grains which are fairly large.

Quenstedtoceras gregarium Bean-Leckenby sp.
Q. turgidum Bean sp.
Aspidoceras hirsutum Bayle.
Lunuloceras conterminum Bean-Leckenby sp.
L. cf. *pompeckji* Parona & Bonarelli.
Oppelia sp.

VERTUMNUS ZONE.

Grey, with a few fairly-large oolitic grains.

Quenstedtoceras vertumnus Bean-Leckenby sp.
Q. aff. *vertumnus.*
Pachyceras rugosum Bean-Leckenby sp.
Oppelia glabella Bean-Leckenby sp.
Siemiradzkia poculum Bean-Leckenby sp.
S. plana (?) Siemiradzki sp.
Hecticoceras ombilicatum Tsytovitch.
H. puteale Bean-Leckenby sp.

Perisphinctes alligatus Bean-Leckenby sp.

This has a bluish matrix, with occasional fairly-large oolitic grains; but there is not much matrix attached.

Bluish, marly, calcareous, with a few oolitic grains.

Aspidoceras faustum Bayle sp.
Quenstedtoceras vertumnus Bean-Leckenby sp.
Q. aff. *gregarium* Bean-Leckenby sp.

LAMBERTI ZONE.

Bluish, somewhat argillaceous, a few large grains.

Quenstedtoceras lamberti J. Sowerby sp.
Q. flexicostatum Phillips sp.

Athleta zone.

Greyish, calcareous, oolitic.

Peltoceras subtense Bean sp.
P. bifidum (?) Quenstedt sp.
Bonarellia sp.=*bipartita* Quenstedt, 'Amm. Schwäb. Jura' 1886–87, pl. lxxxv, fig. 3.

Brown, calcareous, oolitic; mixed with irony sand. Matrix and fossils much iron-stained.

Peltoceras athleta Phillips sp.
P. subtense Bean sp.
P. reversum Simpson-Leckenby sp.
P. propinquum (?) Waagen.
P. cf. *chauvinianum* d'Orbigny sp.
P. murrayanum (?) Simpson-Leckenby sp.
Quenstedtoceras aff. *gregarium* Bean-Leckenby sp.
Q. longævum Bean sp.
Cosmoceras gemmatum Phillips sp.
Cosmoceras jason (?) Reinecke sp.=*elizabethæ* Pratt sp., Ann. Mag. Nat. Hist. vol. viii (1842) pl. iii, fig. 3 (cf. *C. pollucinum* Teisseyre, 'Cephalop. d. Ornatenthone in Rjäsan' Sitzb. k. Akad. Wissensch. Wien, vol. lxxxviii, 1883, pl. v, fig. 30).
C. jason spinosum Quenstedt sp., 'Amm. Schwäb. Jura' 1886–87, pl. lxxxiii, fig. 28.
C. elizabethæ (?) Pratt sp. *op. cit.* 1842, pl. iii, fig. 4 (cf. *C. pollux* Teisseyre, *op. cit.* 1883, pl. iv, fig. 27).

Peltoceras cf. *propinquum* Waagen.
Lunuloceras aplanatum Tsytovitch sp.
L. lahuseni Tsytovitch sp.
Cosmoceras duncani J. Sowerby sp.
Siemiradzkia aff. *comptoni* Pratt sp.

The species below the line show a grey sandstone matrix, which is presumably only a less decomposed condition of the bed. *C. duncani* shows the grey sandstone matrix in the chambers, but the irony sand with oolitic grains outside.

Ornatum zone.

Grey or yellowish grey, with many coarse grains which fall out readily.

Cosmoceras compressum Quenstedt sp.
C. rotundum Quenstedt sp.
C. ornatum (?) Nikitin.
Cosmoceras cf. *transitionis* Nikitin.
Quenstedtoceras placenta Simpson-Leckenby sp.

Kœnigi zone.

Light brown, calcareous, with many small oolitic grains.

Proplanulites kœnigi J. Sowerby sp.
Pr. arciruga Teisseyre.
Cadoceras (?) sp. cf. *chrysoolithicum* Waagen sp.
C. grewingki Pompeckj.
C. sp. nov.=*longævum* Bean sp. *pars.*
Phlycticeras hyperbolicum Simpson-Leckenby sp.
Kepplerites toricellii Oppel sp.
K. sp.=*gowerianum* Phillips sp. *non* Sowerby.

Cadoceras sublæve J. Sowerby sp., in a loose sandy matrix.

The following Yorkshire species, which for various reasons have not yet been thoroughly studied, are tentatively assigned as under:—

TABLE II.—SPECIES AND SUGGESTED ZONES.

Zones.	Species.
Gregarium	*Quenstedtoceras dissimile* Brown sp.
	Ammonites funiferus Phillips.
	Ammonites lenticularis Phillips.
Vertumnus	*Perisphinctes rotifer* Brown sp.
Athleta	*Hecticoceras nodosum* J. Sowerby sp.
do. (grey sandstone)	*Ammonites binatus* Bean-Leckenby=several Perisphinctean forms.
Kœnigi	*Ammonites rowlstonensis* Young & Bird.

These lists of ammonites total nearly sixty species, that is, about double the number which Leckenby mentioned; yet there are certainly several more.

Appended are the original section as described by Leckenby and a more modern section published by Fox-Strangways. It will then be possible to see how these compare with the matrices of the ammonites, and how they can be zoned.

SECTION I. THE KELLOWAY ROCK AT RED CLIFF (LECKENBY).[1]

	Thickness in feet.
'A. Moderately compact irony sandstone, 1½ foot thick, traversed by darkened veins of the same metallic character, across which *Ammonites* are often placed, and which divide the fossil into separate portions when an attempt is made to extract it. This bed is characterized by the presence of *Am. Kœnigi*, *Am. flexicostatus*, and *Belemnites tornatilis*. *Am. flexicostatus* is here special to the bed	[1½]
'B. Loose friable sand and sandstones, without fossils	4
'C. Bed similar to A, but much richer in organic remains, containing, besides *Am. Kœnigi* and *Belemnites tornatilis*, *Am. sublævis*, *A. Gowerianus*, *A. Chamusseti*, *Pholadomya acuticosta*, *Modiola pulchra*, *Terebratulæ*, *Gryphæa dilatata*, and other shells. It is more nodular and cherty than the upper zone, and its fossils are better preserved	1½
'D. Compact sandstone, entirely unfossiliferous, with the rare exception of a stray Belemnite or Ammonite in the centre of one of its huge blocks	20'

SECTION II. THE KELLAWAYS ROCK AT RED CLIFF (FOX-STRANGWAYS).[2]

		Thickness in feet.
	'Shales of the Oxford Clay.	
	Few oolitic nodules.	
All these seem to become one irony rock further west.	Hard band, very oolitic	1
	Soft shaly rock, like Oxford Clay, but much more calcareous. *Belemnites*	9
	Soft sandstone	3
	Red irony rock full of *Gryphæa dilatata*. Oolitic in upper part	6
	Sandstone soft in places, sometimes very hard and siliceous; weathering into large doggers. *Avicula* in lower part	4
	Soft sandstone and hard doggers, few fossils	10
	Soft yellow sandstone with *Gryphæa*, etc.	6
	Yellow sandy shales	8
	Grey shales of the Cornbrash.'	

[1] Q. J. G. S. vol. xv (1859) p. 5.
[2] 'The Jurassic Rocks of Britain: vol. i—Yorkshire' Mem. Geol. Surv. 1892, p. 280.

Leckenby (*op. cit.* pp. 4, 5) mentions a thin band of calcareous pisolite a short distance to the south of Gristhorpe Bay, which immediately underlies the Oxford Clay and is 5 inches thick. He does not seem to have considered this bed of importance, as he does not mention it in his section. But the description seems to fit the matrix of the *vertumnus* zone: its fairly-large oolitic grains might well be described as small pisolites. Such a bed, therefore, should be placed on the top of his section. In that position Fox-Strangways mentions a hard band very oolitic, and 'very oolitic' is a term which exactly describes the matrix of the *gregarium* zone. Further, Fox-Strangways says, of the north side of Osgodby Nab:

'At the top of the rock is a thin band of dark-coloured calcareous shale, with oolitic grains, which also contains many ammonites including a large tuberculated species. This is probably the calcareous pisolite ...' (*op. cit.* p. 281).

This description seems to fit the matrix of the *gregarium* zone. 'A large tuberculated species' of ammonite is very vague: it might be a *Cosmoceras*, a *Peltoceras*, or an *Aspidoceras*; certainly *Aspidoceras hirsutum* Bayle answers well to the description, and that is a species of the *gregarium* zone.

Assuming a general identity of the calcareous pisolite with Fox-Strangways's 'dark-coloured calcareous shale,' then the following suggestion may be made as to the zoning of the sections given by the two authors:—

TABLE III.—ZONES AND SECTIONS OF THE 'KELLOWAY ROCK' CORRELATED.

Zones.	Leckenby.	Fox-Strangways.
Gregarium	Calcareous pisolite.	Hard band, very oolitic.
Vertumnus		
Lamberti		Soft shaly rock, calcareous.
Athleta	A. Irony sandstone.	Soft sandstone.
Ornatum.........		
(?)	B. Sand and sandstone.	Red irony rock.
Kœnigi	C. Irony sandstone.	
(?)	D. Unfossiliferous sandstone.	Three beds of sandstone.

II. REMARKS ON THE FAUNA AND THE ZONES.

Beginning at the base:—Leckenby's bed D, which is above the Cornbrash with *Macrocephalites* (*Macrocephalus* zone), cannot be assigned to any one zone on the evidence now available. His bed C may be regarded as forming the *kœnigi* zone. Above that, on the evidence of South of England strata, should be a zone of *calloviense*: this may be represented by Leckenby's unfossiliferous bed B; but it is noticeable that *Sigaloceras calloviense* appears to be absent from the Yorkshire strata. There is evidently a lacuna here, for the zone of *Reineckeia anceps* is also missing. This zone, which is well shown by Continental deposits, would seem to be entirely absent from Yorkshire, and to have been practically removed from

the Callovian strata of the rest of England: the only evidence for it known to me being a solitary *Reineckeia* from Wiltshire, and another reported by Dr. A. Morley Davies from Dorset. Such isolated finds appear to indicate that the zone was denuded except, perhaps, for a fragment or two left in pockets. But in Scotland at Duart House, in the Isle of Mull, the *Reineckeia-anceps* zone is represented by several species and many specimens; the material was submitted to me for professional work by the Geological Survey of Scotland.

Another Continental zone, that of *Ammonites coronatus* (*Erymnoceras coronatum* Bruguière sp.), occurs about this horizon, above *anceps*. It also must have suffered by denudation. There appears to be no trace of *Erymnoceras* in Yorkshire. In Wiltshire there is a representative, *E. reginaldi* Morris sp.: this appears to have been not uncommon, and is quoted from a rock-band about 10 feet above '*Ammonites jason*.'[1] From the brickyard, Calvert Station (Buckinghamshire), I have the same species; this exposure shows about 90 feet in the so-called '*ornatum* zone.' In the *ornatum* zone of Oxford the species or its allies appear to be wanting; perhaps these strata represent only the upper part of the Calvert series.

The *ornatum* zone in the Kelloway Rock of Yorkshire is represented by a stratum with coarse oolitic grains, yielding several species of *Cosmoceras*. Other species of the genus show a more iron-stained matrix, which is similar to that yielding many species of *Peltoceras* (*athleta* zone); but perhaps the iron-staining of the *Cosmocerata* is deceptive, being due to filtration from a superior stratum. These *Cosmocerata* are remarkable for their large size, and in some cases for their robust proportions; they are unlike the usual *ornatum*-zone series found in the Midlands. And the series of *Peltoceras* is more varied than in the Midlands: *P. reversum* is a very noticeable form, quite suggestive of *P. transversarium* Quenstedt sp. and *P. toucasianum* d'Orbigny sp., which are from the Argovian.

On the evidence of Fox-Strangways's section, where calcareous shaly rock follows above soft sandstone resting on the irony bed, the zone of *lamberti* is next in order above that of *athleta*, for the matrix of the species examined and placed in this zone is the only one which seems to correspond with his description. Apparently, however, there is much difference in the *lamberti* zone of Yorkshire, as compared with that of counties south of the Humber; the former is much less fossiliferous than the latter.

Above the *lamberti* zone comes the *renggeri* zone, well developed in Buckinghamshire and on the Continent, and very fossiliferous. I have seen no evidence for this zone among the Yorkshire specimens

[1] R. N. Mantell, 'Strata . . . exposed . . . near Chippenham, &c.' Q. J. G. S. vol. vi (1850) p. 313; *Ammonites reginaldi* is figured in pl. xxx, fig. 6.

examined; but, as Fox-Strangways quotes *Ammonites crenatus* from the Kellaways Rock of Yorkshire (p. 277), and as *A. crenatus*, or rather a *Creniceras*, is fairly unmistakable, it is reasonable to conclude that there is some trace of the *renggeri* zone. At the same time, the lack of the associated fauna would seem to indicate a poor development. Its position is presumably in the calcareous shaly rock.

There remain yet two matrices, two zones, to be accounted for —*vertumnus* and *gregarium*: the former answers to Leckenby's calcareous pisolite and the latter to Strangways's 'hard band, very oolitic' or to his 'dark-coloured shale with oolitic grains,' which he thinks is the equivalent of Leckenby's rock. At any rate, both authors find this stratum, or these strata, at the top, close under so-called 'Oxford Clay.'

The *vertumnus* zone shows a fauna which differs considerably from any fauna found, so far as my experience goes, in the rest of England.

Aspidoceras faustum, *Quenstedtoceras vertumnus*, *Q.* aff. *gregarium*, *Pachyceras rugosum*, *Oppelia glabella*, *Siemiradzkia poculum* are all species which seem to be special to Yorkshire as distinct from the rest of England, leading to the inference that the Oxford Clay deposits of the Midlands and the South are incomplete. *A. faustum* and *S. poculum* are found in Normandy, where also are found species of *Pachyceras* allied to *P. rugosum*. *A. faustum* is remarkable for its likeness to certain forms of *Aspidoceras* found in the Lower Calcareous Grit (basal Argovian) of Oxford and the neighbourhood, but that corresponds to a much higher stratum in Yorkshire.

The *gregarium* zone also shows a fauna peculiar to Yorkshire, as compared with the rest of England. *Quenstedtoceras gregarium* is most like some Russian species. *Q. turgidum* and *Aspidoceras hirsutum* are found in France.

It is obvious that, at present, it is not possible to say which is the higher of the two matrices and the two faunas. The sequence now indicated is a supposition; but the calling of attention to it may be the means of obtaining the required solution. It is presumed that these strata represent in a general way the *mariæ* zone of the Normandy coast, and the likeness of *Quenstedtoceras vertumnus* to *Q. mariæ* favours this view. But I have seen no evidence as yet for any *mariæ* fauna in the Oxford Clay of the rest of England.[1]

A few words may now be said about the Oxford Clay of Yorkshire. Fox-Strangways (*op. cit.* p. 295) quotes fifteen ammonites

[1] Identifications of *Ammonites mariæ* cannot be accepted without investigation: A. d'Orbigny mixed several forms. (See below, p. 164.)

from it, but eight of these he also gives as from the Kellaways Rock. Of the remainder, three more are of the age of the 'Kelloway Rock,' as developed in Yorkshire: that is to say, *Ammonites comptoni* and *A. elizabethæ* are species of the *ornatum* zone, while *A. eugenii* belongs to the *athleta* zone.

This leaves only four species. Of these, two, *A. cordatus* and *A. vertebralis*, are, when correctly identified, species of the Lower Calcareous Grit as developed in the Oxford district. But in the top layer of Oxford Clay, subjacent to the Lower Calcareous Grit, is a fauna with several *Cardioceras*-like species, which are often incorrectly assigned to *A. cordatus* and *A. vertebralis*. Such a fauna, which must be worked out another time, may be indicated by the citation of these species from the Oxford Clay of Yorkshire.[1]

There remain now only two species, *A. vernoni*[2] and *A. oculatus*.[3] By the kindness of the authorities of the York Museum, which I gratefully acknowledge, the types of these two species have been placed in my hands for study. So far as I know, they are quite peculiar to Yorkshire. They may have lived contemporaneously with the *Cardioceras*-like species, or they may indicate another date.[4] It will not commit us, then, irretrievably to mark the Oxford Clay of Yorkshire, which is not contemporaneous with the 'Kelloway Rock,' as being of *vernoni* hemera, until the facts can be more accurately ascertained.

There is yet another species from the Oxford Clay of Yorkshire, *Peltoceras intertextum* Simpson sp.[5] incorrectly assigned to the Lias by its author. But it is a derived fossil and is pyritized, and is, moreover, an Oxford Clay form. It is probably from the *athleta* zone, where that zone is argillaceous and not calcareous. My thanks are due to the late Mr. T. Newbitt, F.G.S., and the authorities of the Whitby Museum for kindly allowing me to have the type for study.

The results of the foregoing remarks may be stated graphically as follows (Table IV, p. 160):—

1 A flat (? thin) form of the so-called '*Am. cordatus*' is presumably *Am. scarburgensis* Young & Bird, which is thus described ('Geol. Surv. Yorkshire Coast' 2nd ed. 1828, p. 265):—'We have a small ammonite resembling this [*A. speetonensis* Bean] on the side, but very flat, and with a crenated keel, found by Mr. Williamson in the second shale [Oxford Clay] at Scarborough. This species may be named *A. scarburgensis*.'

2 'Geol. Surv. Yorkshire Coast' 2nd ed. (1828) pl. xiv, fig. 5.

3 J. Phillips, 'Geol. Yorkshire' vol. i (1829) p. 138 & pl. v, fig. 16.

4 In certain MS. lists of Jurassic zones which I drew up for the Geological Survey, I used the term 'pre-*cordatus*' for these *Cardioceras* strata of the Oxford Clay which underlie the Calcareous Grit where *C. cordatum* occurs. This provisional term was necessary, because there are no correctly identified ammonites to give a name.

5 'Fossils of the Yorkshire Lias' 1855, p. 50.

TABLE IV.

TIME-TABLE AND COMPARISON OF CALLOVIAN-DIVESIAN (OXFORDIAN) DEPOSITS.

	Hemeræ.	Strata: Yorkshire.		Strata: Midlands, etc.		Remarks.	
DIVESIAN.	*vernoni*	Oxford Clay.					
	gregarium ...	Oolites at top of Kelloway Rock locally developed.	Oxford Clay according to quoted fossils at other places.		No evidence of fauna or deposit.	*Mariæ* Zone of Normandy Coast.	
	vertumnus ...						
	renggeri	A trace of the fauna.			Well developed in Buckinghamshire Upper Oxford Clay.		
	lamberti	Kelloway Rock locally.	Passes laterally into Oxford Clay according to quoted fossils.				
CALLOVIAN.	*athleta*			Lower Oxford Clay	*Athleta* Zone, Oxford. Perhaps incomplete.	Late	development of *Cosmoceras*.
	ornatum				Clay with *Cosmoceras*, Oxford.	Middle	
	coronatum ...	Neither fauna nor deposit found.			*Reginaldi* Bed, Trowbridge.	Early	
	anceps				Trace of fauna in Kell. R. Wilts. Deposit nearly removed.	Deposit with good *Reineckeia* fauna, Isle of Mull, Hebrides.	
	calloviense ...	Fauna and deposit may be present.			Kellaways Rock.	Kellaways Rock. H. B. Woodward.	
	kœnigi.........	Kelloway Rock (Leckenby).				Kellaways Clay. H. B. Woodward.	

The foregoing Table shows that the 'Kelloway Rock' of Yorkshire is, in the main, contemporaneous with the Oxford Clay of the Midlands and the South of England, and is therefore later than the Kellaways Rock of these parts. It also shows that, according to the evidence of the Oxford-Clay fossils of Yorkshire cited by Fox-Strangways,[1] the 'Kelloway Rock' of Yorkshire is

[1] The following table shows the zones which the ammonite species cited by Fox-Strangways from the Oxford Clay of Yorkshire may be presumed to indicate; some records have been interpreted:—

TABLE V.—'OXFORD CLAY' AMMONITE ZONES.

vernoni	*A. vernoni*, *A. oculatus* (*A. cordatus*, *A. vertebralis*=*Cardioceras* spp. may be higher).
gregarium	*A. perarmatus*=*Aspidoceras hirsutum* Bayle.
vertumnus	*A. mariæ*=*A. vertumnus*.
renggeri	*A. crenatus*=*Creniceras* sp.
lamberti	*A. lamberti*.
athleta	*A. binatus*, *A. eugenii*.
ornatum	*A. elizabethæ*, *A. comptoni*.

There is also *A. crenularis* Phillips, 'Geol. Yorks.' vol. i (1829) pl. xii, fig. 22, probably a *Quenstedtoceras*, and presumably from the *lamberti* zone.

only developed locally so far as certain of its beds are concerned, and that even within the county itself it passes laterally into, and is contemporaneous with, the Oxford Clay.

The idea that the Kellaways Rock and the Oxford Clay were always and wholly sequential deposits, carried out in our literature and in the museum arrangement of specimens,[1] where the same species are found in a lower case headed 'Kellaways Rock' and in a higher case labelled 'Oxford Clay,' is one which must be abandoned. These stratigraphical terms are misleading: they do not indicate sequential deposits, but beds which were in the main contemporaneous. All that they indicate is the lateral change from arenaceous or calcareous to argillaceous conditions.

It is suggested that for the earlier deposits the term 'Callovian' be retained; the Callovian will then roughly coincide with the development of the genus *Cosmoceras* and its allies *Kepplerites* and *Sigaloceras*. For the later deposits the term 'Divesian' (Dives, Calvados) has been suggested to me by Prof. Welsch; it marks the development of *Quenstedtoceras*. When *Quenstedtoceras* is replaced by *Cardioceras* (Lower Calcareous Grit, Coral Rag, and, perhaps in some cases, highest layer of Oxford Clay) the term should be 'Argovian' for *Cardioceras*-yielding strata following Divesian.

These terms would be uniform; but the terms 'Oxford Clay,' 'Kellaways Rock,' etc., are useful, if it be remembered that they vary in value in different localities.

It is inadvisable to use 'Oxfordian' for Divesian, because in Continental usage 'Oxfordian' stands mainly for Argovian (Oxford Oolites).

The suggestion illustrated in Table IV is that the Callovian-Divesian deposits are locally incomplete; that the deposits of certain hemeræ have been locally removed by penecontemporaneous erosion, as is usual with deposits of the Bajocian, Aalenian, etc.; that a full sequence of deposits can only be obtained by placing together the developments of many localities; and that, to express the entire sequence, a full table of zonal or hemeral names, such as is now given, is necessary. The object of a full table of hemeral names is to obtain a true record of the sequence of ammonite faunas as a necessary prelude to a study of their development.

A theory of unrepresented zones may explain in part why the ammonite fauna of certain beds is so peculiar to Yorkshire; but in other cases, where zones are represented, and yet there is distinctive peculiarity, that explanation fails. It may then be necessary to

[1] Such statements have given much trouble: see J. F. Pompeckj, 'Jur. Fauna of Cape Flora' Norwegian North Polar Exped. vol. i (1900) No. 2, p. 120. The Professor rightly judges that 'the Kellaways Rock and the Oxford Clay [of English geologists] may be petrographically different facies of faunistically corresponding strata'; but then he adds, 'and in both the Kellaways Rock (especially that of Yorkshire) and the Oxford Clay, the different zones of the Callovian, as they may be observed on the Continent, cannot be separated.' That statement is disputable: the Yorkshire specimens, from their different matrices, are easily separable into zones in the study, and that must be possible in the field.

suppose that at times there was not free communication between the districts north and those south of the Humber.

It is now for the Yorkshire geologists, or those who have the opportunity to work the Yorkshire cliffs, to ascertain how far the facts in the field agree with this armchair stratigraphy. Here, at any rate, are the suggested points for consideration; and, if only building operations or slips of Boulder Clay have not concealed the important beds, observation of the zonal sequence should not be difficult. Further facts will be welcome, whether they confirm or contradict the present suggestions. The object is to call attention to the knowledge required, and to put forward something which may be a working hypothesis—something which may stimulate the attainment of further knowledge.

Examinations of old collections may be useful, but it must be remembered that the labels of localities in collections are not to be trusted. Yorkshire and Wiltshire specimens have been mixed, and specimens from the Scarborough Limestone (Bajocian) and Scarborough 'Kelloway Rock' have been interchanged. But they can all be separated by examination of matrices: the matrix is really the most trustworthy label that a fossil possesses.

III. Palæontological Remarks.

Ammonites ordinarius Bean-Leckenby (Leckenby, p. 8). I have reason to think that this is not a 'Kelloway Rock' species, but is from the Calcareous Grit, and has been wrongly placed and perhaps wrongly localized. If so, it is a *Cardioceras* more or less nearly identical with *Am. goliathus* d'Orbigny (pl. cxcvi, figs. 1 & 2 only), and it may be a synonym of *Nautilus ammonoides* Young & Bird.[1]

Cadoceras grewingki Pompeckj.[2] This species is hardly a true *Cadoceras*, but it belongs to a series which in form and appearance is intermediate between *Cadoceras* and *Quenstedtoceras*. This species and its allies occur in the Kellaways Rock of Kellaways, and have been placed sometimes as *Ammonites mariæ* d'Orbigny. The 'Russian variety' which he figures by that name[3] belongs to the *grewingki* series, but the other examples are quite distinct (see *Q. mariæ*, p. 164).

Cadoceras, sp. nov. Some of Bean's examples of *Am. longævus* belong here as a much compressed ally of *C. grewingki*. The form is also near to *Quenstedtoceras primigenium* Parona & Bonarelli.[4]

Cadoceras sublæve J. Sowerby sp. By this name is intended the small form figured in the lower right-hand corner of Sowerby's

1 'Geol. Surv. Yorks. Coast' 2nd ed. (1828) p. 271.
2 'Jura-Fossilien aus Alaska' Verhandl. K. Russ. Mineral. Gesellsch. ser. 2, vol. xxxviii (1900) pl. vi, figs. 1–3.
3 'Terr. jurassiques: Céphalopodes' 1842–49, pl. clxxix, figs. 7 & 8 only.
4 'Call. inf. Savoie' Mém. Acad. Savoie, ser. 4, vol. vi (1895) pl. ii, fig. 4.

plate ('Min. Conch.' vol. i, 1812, pl. liv), leaving the more globular form as a matter of convenience under the name *C. modiolare* Lhywd-d'Orbigny sp., of which A. d'Orbigny's figure[1] would be the type.

From Gristhorpe Bay I have a fragment of *C. sublæve* as above defined. It is from a matrix of loose sand, suggesting Leckenby's bed B, but he says that this is unfossiliferous.

C. sublæve (+*modiolare*) would appear to be easily identifiable; but in one case it has been very much misunderstood (see below, *Pachyceras robustum*).

Pachyceras rugosum. Bean's *Ammonites rugosus* is a species of the rare genus *Pachyceras*, differing sufficiently from *A. lalandeanus* d'Orbigny. I cannot recall any other record of an English species of the genus.

Pachyceras robustum, nom. nov. This is founded on *Stephanoceras sublæve*, E. E.-Deslongchamps, 'Foss. Oxford. Coll. Jarry; Notes Paléontologiques,' vol. ii (1889) pl. i, figs. 2–4, taking fig. 4 as the type. Prof. Pompeckj[2] has noticed that the species is not identical with Sowerby's *Am. sublævis*, but he has failed to see that it is not a *Cadoceras*, for he has definitely assigned it to that genus. However, the straight massive ribs and the nodose ornament strong on the umbilical border show that it is not a *Cadoceras*: it belongs to the genus *Pachyceras*, and like this genus but unlike *Cadoceras* it becomes less inflated with age.

P. robustum is near to *P. rugosum*, but has more pronounced ornament and strong umbilical nodosities, of which *P. rugosum* shows only traces. *P. rugosum* is also thinner. The position of *P. robustum*, *lamberti* beds of Villers-sur-Mer (= *lamberti-gregarium* zones, perhaps, of this paper), is correct for a *Pachyceras*, but is incorrect for a *Cadoceras*—a genus which belongs to the Lower Callovian.

P. robustum shows that the genus *Pachyceras* is an offshoot of the genus *Erymnoceras*: the study of *P. rugosum* had already led me to form the same conclusion. *P. robustum*, *P. rugosum*, *P. lalandeanum* form in this order a good catagenetic series, in which ornament and thickness are decreasing.

The identification of *P. robustum* with *Ammonites sublævis* and as a *Cadoceras* is good testimony to the deceptiveness of homœomorphy in certain cases, and the likeness thus testified to is an example of a rather unusual form of homœomorphy (see § IV, 'On Development & Homœomorphy' p. 165).

Peltoceras murrayanum. There must be some error in Simpson's description given by Leckenby (*op. cit.* p. 10). To describe a species of this genus as 12 inches in diameter but only three-quarters of an inch thick, must be incorrect; yet the description

[1] 'Terrains jurassiques: Céphalopodes' 1842–49, pl. clxx.

[2] 'Jurassic Fauna of Cape Flora' Norw. North Polar Exped. vol. i (1900) No. 2, p. 79.

obviously refers to a *Peltoceras.* I have received from the Whitby Museum a specimen supposed to be the type. It is rather more than 2 inches in diameter, and is then three-quarters of an inch thick; but it does not altogether agree with the description. Further search for any specimen so named by Simpson may be requested of those who have charge of old collections of Scarborough fossils.

PELTOCERAS SUBTENSE. Leckenby identified this doubtfully with *Ammonites arduennensis* d'Orbigny, but it is not that species. The regular radial (versiradiate) costæ, which bifurcate about the middle of the lateral area, distinguish it from d'Orbigny's species. The position of furcation distinguishes it from many other species. It is a much compressed form, carrying the costate stage a long time, and hardly attaining to the bituberculate stage. The largest example is 176 mm. in diameter.

PHLYCTICERAS HYPERBOLICUM. Simpson's *Ammonites hyperbolicus* is a most remarkable and interesting species. It is the senile development of the genus *Phlycticeras*,[1] which, so far as I recollect, has not yet had any of its species recorded from England. It has lost nearly all ornament, though there remain just sufficient traces of rib-contour to indicate the generic association. The keel has been reduced to a mere ridge. Such a senile species of the genus has not, so far as I know, been recorded.

QUENSTEDTOCERAS GREGARIUM. This species has as a distinctive feature ribs much forwardly inclined across the whorl (prorsiradiation). A Russian species, *Amaltheus leachi* Nikitin[2] (*non* Sowerby), has the same style of tangential ribbing—as if the periphery had been turned forwards around the centre; and it has much the same proportions. Another Russian species, *Amaltheus rybinskianus* Nikitin,[3] is what one would expect as the involute stouter-whorled development. I have not seen such tangentially ribbed forms from any other English localities where other *Quenstedtocerata* abound.

QUENSTEDTOCERAS LONGÆVUM. Leckenby's placing of this as a synonym of *Ammonites lamberti* Sowerby was not correct. The Bean types show two species belonging to two different stocks, one is near to *Q. placenta* (see below) and the other belongs to the *Cadoceras-grewingki* series (see *Cadoceras*, sp. nov., p. 162).

QUENSTEDTOCERAS MARIÆ. D'Orbigny ('Terr. jurassiques: Céphalopodes' pl. clxxix) has several forms under this name. It is

[1] *Phlycticeras* Hyatt = *Lophoceras* Parona & Bonarelli. For a treatise on the species see their work, 'Call. inf. Savoie' Mém. Acad. Savoie, ser. 4, vol. vi (1895) p. 90.

[2] 'Die Jura-Ablagerungen zwischen Rybinsk, &c.' Mém. Acad. Imp. St. Pétersb. ser. 7, vol. xxviii (1881) No. 5, pl. i, fig. 5.

[3] *Id.* pl. i, fig. 8.

advisable to fix one as the type, and for this the example depicted in his figs. 5 & 6 is selected. I understand that this occurs high in the Divesian; but it is doubtful whether we have it in England. The Russian variety (figs. 7 & 8) has nothing to do with it, and probably occurs low in the Callovian. See *Cadoceras grewingki* (p. 162).

QUENSTEDTOCERAS PLACENTA. This very involute species is not a true *Quenstedtoceras*, but still less is it a *Cadoceras* of the *grewingki* series. It would seem to be peculiar to Yorkshire.

QUENSTEDTOCERAS TURGIDUM. This is a senile form, like the example which A. d'Orbigny has ascribed to *Ammonites lamberti* ('Terrains jurassiques: Céphalopodes' pl. clxxviii only), but with a more trigonal whorl, and the venter is more acute in the costate stage.

QUENSTEDTOCERAS VERTUMNUS. This is a species with stout ribs, which look like pieces of cord wound round the whorl. I have not seen it from any other locality. Dr. Pompeckj rightly associates it with *Q. mariæ* d'Orbigny sp., but it is not 'a modification of a *Quenstedtoceras mariæ* d'Orb. sp. with a wider umbilicus':[1] rather is *Q. mariæ* the involute inflated development of *Q. vertumnus*.[2]

IV. ON DEVELOPMENT AND HOMŒOMORPHY.

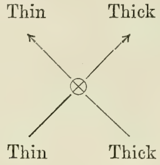
There is an interesting repetition in development, leading to homœomorphy, in many of the Middle Jurassic ammonites. They pass repeatedly and independently from evolute compressed to involute inflated, in some cases to sphærocones, a phenomenon which may be observed in the Callovian genera *Cadoceras*, *Phlycticeras*, in the Divesian *Quenstedtoceras*, and in the Argovian *Cardioceras*. (A similar line is followed by the Kimmeridgian *Amœboceras*, but is not carried so far.) The same phenomenon is also repeated again and again in the different stocks of these various genera quite independently. This phenomenon has caused much confusion in the identification of the various species, and has led to much 'lumping,' because it was not understood. And the 'lumping,' or the failure to recognize what were the critical points of distinction, underlying the likeness, has caused stratigraphical lists to be invalid, and has also given a wholly false range to some much-quoted species, thereby impairing stratigraphical correlation. And that the likeness, the homœomorphy, should have caused the 'lumping is the best testimony to its completeness. The likeness is often the greater when, as is so frequently the case, the loss, or nearly so, of the principal distinctive characters (ornament, keel, etc.) has accompanied the inflation.

Other genera not dissimilar in time and in appearance, *Macrocephalites, Erymnoceras, Pachyceras*, develop in a different direction—

[1] J. F. Pompeckj, 'Jurassic Fauna of Cape Flora': Norw. North Polar Exped. vol. i (1900) No. 2, p. 97.
[2] See § IV, 'On Development & Homœomorphy.'

as they become involute and more aged[1] they lose inflation, and by this criterion they may be distinguished from the preceding series of genera.

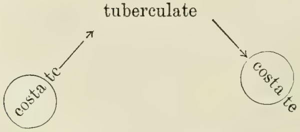
Now, when one series is travelling from thin to thick and another from thick to thin, there is every possibility of their reaching a median collision-point, thus :—



At the median point, given certain factors, there would be homœomorphy : not the homœomorphy of subparallel lines of development as in the first-quoted genera, but the more interesting—and, by the nature of the case rarer—phenomenon of homœomorphy of crossing lines of development. The very interesting case of *Pachyceras robustum* and *Cadoceras sublæve* mentioned above (p. 163) is an example, and a very good example, of such homœomorphy. It caused incorrect identification and, in consequence, an unwarranted extension of the zonal range of *Cadoceras*.

Homœomorphy of the first kind may be called parallel homœomorphy, that of the second transversal homœomorphy: these terms refer to the manner in which the phenomenon was produced. Isochronous and heterochronous homœomorphy state whether the homœomorphous species lived in the same or at different times.

There is yet another mode of producing homœomorphy, and this may be called cyclical homœomorphy. It arises when a species in the course of its development retraces its tracks : that is to say, when a species showing a catagenetic stage apes one in an anagenetic stage. For example, an anagenetic species is in the pre-tuberculate costate stage, the catagenetic species is in the post-tuberculate costate stage. The position may be illustrated diagrammatically thus :—



The circles represent the main stages of the two species which

[1] There would be renewed evolution (outcoiling) in extreme old age (incipient scaphiticone stage).

look like enough to be confused (are homœomorphous) until they are analysed ontogenetically, which is not always done.

Such a heterochronous case, partly concerned with species dealt with in the present paper, is not of the most striking kind, but it deserves mention; it is the case of the young costate *Peltoceras*, like enough to *Dactylioceras* of the *communis* type to cause the former to be sometimes labelled as the latter and relegated to the Lias. Now the former is anagenetic (renewed anagenetic, perhaps), it is in the pre-tuberculate costate stage; the latter is catagenetic, it is in the post-tuberculate costate stage.

By attention to the various phases of homœomorphy the apparent tangle of ammonite species and the apparent anomalies of stratigraphical records are found to come into definite order. Then it is seen that the many names for genera and species are insufficient to express the facts, and that more names will give a clearer picture of the lines of evolution—that they are a real help to the memory, and not a hindrance.

Discussion.

Mr. J. W. Stather remarked that the beds from which the old collections were obtained are now inaccessible, being covered by buildings at Scarborough and by landslips at Gristhorpe. These fossiliferous beds occur in the uppermost part of the Kellaways Rock, the remainder of the formation being practically unfossiliferous. He mentioned that the best opportunity for obtaining Kellaways fossils in Yorkshire, during recent years, was in the cutting on the Hull & Barnsley Railway at South Cave, and he hoped that the Author would examine the collections made by the local geologists from that locality.

Mr. L. F. Spath congratulated the Author on his most interesting paper and the Society on receiving that valuable palæontological contribution. When he thought of the state of hopeless confusion in which Hyatt had left the classification of these Callovian (as, indeed, of all other) ammonites, putting such closely allied genera as, for example, *Sigaloceras* and *Kepplerites* or *Erymnoceras* and *Reineckeia*, not only into different families, but different super-families, and when he remembered the misdoings of the French school, who at the present day included in the Oxfordian genus *Pachyceras*, so ably traced by the Author that evening, even certain Portlandian holcostephanoids, he felt that all palæontologists must look forward to a study of the details of this paper with the greatest interest.

A point to which he desired to draw attention was the use of the terms Callovian and Oxfordian. There was hardly a stratigraphical term which was employed less definitely and less satisfactorily at the present day than those terms Callovian and Oxfordian, not only on the Continent, but also in this country. In one great London museum, for example, even Kimmeridge-Clay ammonites were labelled 'Oxfordian.' In the speaker's opinion

the Society was greatly indebted to the Author for his table of zones, which indicated how the terms Callovian and Oxfordian, or preferably Divesian, might profitably be employed. His classification was not the orthodox one, but it rested on a sound palæontological basis.

Dr. A. M. Davies said that those geologists who were interested in the Upper Jurassic strata should rejoice in the knowledge that the Author was turning his attention to the zoning of those rocks. It was certain that the number of Upper Jurassic zones would have to be increased.

The President (Dr. A. Strahan) reminded the meeting that the relations of the Kellaways Rock of Yorkshire to the Oxford Clay, and the fact that it was not strictly correlative with the Kellaways Rock of Wiltshire, had been pointed out by the late Mr. Hudleston many years ago. He enquired whether it was contemplated that the misspelling 'Kelloway' could or ought to be perpetuated. The phenomena described under the names of cyclical and transversal homœomorphy appeared to be of great interest and to deserve close scrutiny.

The Author, in reply, remarked that the spelling 'Kelloway Rock' was not his, and he had merely adopted a suggestion made, he believed in the first place, by the late Mr. Hudleston, to keep 'Kelloway Rock' for the Yorkshire bed and 'Kellaways Rock' for the more limited Wiltshire stratum, as a temporary measure. In conclusion, he heartily thanked the Fellows for their kind reception of his paper.

10. *The* Derived Cephalopoda *of the* Holderness Drift.

By Charles Thompson, B.Sc. (Communicated by G. W. Lamplugh, F.R.S., F.G.S. Read January 22nd, 1913.)

Contents.

I. Introduction.

For a long time it has been common knowledge among geologists that the Drift of Holderness, and of the Yorkshire coast generally, yields specimens of Jurassic cephalopoda, and at one time these specimens were assiduously collected.

Early in the last century, Phillips, in his classic 'Illustrations of the Geology of Yorkshire,'[1] stated that fully three-fourths of the then known species of the fossils of the Lias could be found in the 'Diluvium.' Again, Simpson and J. F. Blake, in their respective writings, mention certain fossils as being more abundant in the Drift of Holderness than in the known exposures of the Lias.

Since those authors wrote, the remanié fossils have been ignored until recently. There are now, however, two large collections of ammonites from the Boulder-Clay cliffs themselves, and also from the beach-stones derived presumably from the same clay. The one has been made by Mr. William Morfitt of Atwick, the other by myself and my colleague, Mr. A. H. Denham, of Hymers College, Hull.

These two collections, along with other smaller ones, show that Phillips almost certainly understated the proportion of known forms obtainable from the Drift. It is more probable that practically every species of the multiform Liassic ammonites known from Yorkshire exposures has also been found, or can be found, in the Drift.

Beside this stands the important fact that in the clay itself and in the beach-stones there have now been found many fossil cephalopods which, so far, have never been obtained, or at least recorded as obtained, *in situ* in the Yorkshire Lias. The Oolitic and Cretaceous forms are, however, less fully represented, though the Speeton

[1] 'Pt. 1—the Yorkshire Coast' 1829, pp. 176–77.

Clays (Lower Cretaceous) have yielded abundant material to the Glacial ice, so that Mr. Morfitt has been able to gather a beautiful set of those remarkable globose forms which distinguish the Valanginian fauna, and are so rarely found in place at Speeton.

A point of much importance in connexion with these fossils from the Drift is that, when one examines the matrices of many of them, it is seen that the rock cannot be now matched within the borders of our county, and the pertinent question arises: Whence have they been transported?

I dealt briefly with the subject in a preliminary note and list published in the Transactions of the Hull Geological Society for 1910; but in the present paper I propose to offer a more comprehensive and up-to-date account, in which are included the results of my later researches and of my examination of all available specimens in the possession of other collectors and in the various museums. The net result is that the previous list of ammonites has been more than doubled in these last two years.

II. The Liassic Ammonites, etc. from the Drift, and their Matrices.

Planorbis and lower (?) Beds.

Taking species in their recognized stratigraphical order, the first on the list is *Psiloceras (?) hagenowi* (Dunker, Quenst.). My colleague obtained several specimens from a block of very fine-grained, hard, splintery, ferruginous limestone. These specimens were the first representatives of the species to be recognized from an English source. Mr. Buckman confirmed my determination, and has since found two specimens in the Tate & Blake Collection at the Museum of Practical Geology, Jermyn Street. This species is a remarkable one, for it has well-defined ceratite suture-lines, with smooth rounded saddles and but slightly corrugated lobes. The rock may actually be a relic of the marine Trias, or may be from some passage-bed not developed, or at any rate not yet found, on land in this country. The species occurs on the Continent in Northern Germany, Bohemia, the North-Eastern Alps, and Switzerland. So recently as last August another fragment of this species was seen on the face of a block of the same kind of limestone, several miles from the place where the first was found. There is no matrix known at present in the English Trias, or in the Yorkshire Lowest Lias, resembling this.

Most of the English lists, if not all, give two species of ammonites only—*Psiloceras planorbis* and *Caloceras johnstoni*—as being found in the *Planorbis* Zone. This restriction is remarkable, for in all the other zones of the Lias there are many representative species of the ammonite race.

That it is not true of the beds of this zone laid under contribution by the ice-sheet is shown by the fact that, from the many

derivative specimens of *Psiloceras* submitted to Mr. Buckman, he has identified the following:—

Psiloceras cf. *brevicellatum* Pompeckj.
Ps. erugatum (Bean-Phillips).
Ps. erugatum ? (Bean-Phillips).
Ps. cf. *læve* (Quenst.).
Psiloceras cf. *plicatum* (Quenst.).
Ps. provinciale ? (Quenst.).
Ps. cf. *psilonotum* (Quenst.).
Psiloceras sp. nov.

This list implies that there is much careful work still to be done on this genus, and that English lists will receive some addition to their scanty tale of two.

It is of interest to observe that *Psiloceras provinciale (?)* and the new species are very similar to several figured by Dr. F. Wähner[1] and recorded as occurring in a yellowish-grey limestone, together with *Wæhneroceras megastoma*, at Schreinbach. They are, therefore, of a later age than *Ps. planorbis* itself. Our specimens differ in having somewhat less complicated suture-lines. The Schreinbach forms possess very much foliated suture-lines, and the whorls are more inflated.

In our own collection there are more examples of *Ps. erugatum* than of any other form. Other collectors, however, possess more specimens of the *Ps. læve* type, which I believe are very similar to, if not identical with, the German type styled *Ps. læve.*

The matrix of the specimens is generally a crystalline shelly limestone, but in a few cases a tough fine-grained earthy one. The colour of the rock is usually pale grey, sometimes it has a brownish tinge. As in Tate & Blake's time, so now, there is no locality in Yorkshire where these limestones can be seen in place.

It is evident from the character of these lowest limestones that, although they do not indicate a deep sea, they do indicate a clear one, free, or nearly free, from the dark mud of the succeeding zones. This may indicate either remoteness from the coast-line of the time, or the absence of mud-bearing currents.

Caloceras Beds.

On the Continent, between the *Planorbis* Zone and that of *Schlotheimia angulata*, there is a so-called '*Caloceras* Bed,' but this bed has never yet been identified in Yorkshire. In the Drift, however, many specimens are found of the genus *Caloceras* with fairly stout whorls, which may at present be collected under the specific names of *C. johnstoni* (Sow.) and *C. belcheri* (Simpson).

The specimens of this series (with one exception) have not been submitted to Mr. Buckman; but, from the varying suture-lines and ornamentation, I am impelled to the conclusion that there are more than two species in the Boulder Clay. Most of the specimens are beautiful casts in calcite. The matrices are all hard limestones, and no other ammonite has yet been found associated with them in the same block. As a rule, there is no other fossil visible in the boulder.

[1] 'Zonen des Unteren Lias' Beitr. Pal. Œsterr.-Ung. vol. iii (1884) pl. xxiii (xi) figs. 6 *a* & 7 *a*.

We have not yet been able to confirm Blake's statement[1] that *C. johnstoni* is found 'in nodules on the coast,' as well as '*in situ* at Redcar,' but it is well to bear in mind that one positive fact is worth more than any amount of negative evidence.

When reviewing the very slender whorled series belonging to this genus, one finds that until this year (1912) these very slender forms have disclosed themselves by only the poorest of fragments, although search has been made for them for many years. Quite recently, however, I found a boulder containing beautifully preserved specimens, the best that I have ever seen. Mr. Buckman identifies them as follows:—*Caloceras laquem* (Quenst.), *C.* cf. *laquem* (Quenst.), and *C. allasii* (Brown).

Neither Simpson nor Tate & Blake, although truly indefatigable collectors, found these beautiful narrow-whorled forms in the north of the county. Again, as in the case of *Psiloceras*, work has still to be done on the English specimens of this genus.

It is rather a remarkable fact that I have not found one specimen of any of the preceding forms in the Boulder-Clay cliffs themselves. All these older forms come from the beach-stones, as if washed from a clay which is suffering submarine erosion.

Angulata Beds.

Dealing now with fossils from the zone of *Schlotheimia angulata*, one finds evidence of different conditions. Many specimens occur in the cliffs themselves, especially at Filey, but representatives of the species are scattered all along the Holderness coast as well. As a rule, instead of occurring in blocks, each specimen, complete or fragmentary, is found alone, and is generally in a gritty blue matrix of shale. This shale evidently weathered easily, for the fossils are comparatively clean. Most of these specimens are crushed. So far, we have found only one boulder of hard pale limestone containing this genus (*Schlotheimia*); and, as the small fossils which the boulder contained were mere casts in clear glassy calcite, not much was secured from it.

One of the specimens, which apparently came from a clay, was identified by Mr. Buckman as *Schlotheimia exechoptycha* (Wähner). He considers two other specimens of the genus submitted to him to be new forms. The collections made by others along the coast contain several specimens comparable with *Schl. trapezoidalis* (Sow.), while we possess one which may be placed with *Schl. ventricosa* (Sow.).

Bucklandi Beds.

The derived fossils from the *Bucklandi* Zone deserve special note, for they are probably the most numerous of any, in consequence of so many boulders of hard dark bluish limestone presenting themselves to the hammer of the collector.

[1] R. Tate & J. F. Blake, 'The Yorkshire Lias' 1876, p. 271.

Coroniceras rotiforme, although entered as doubtful in Yorkshire lists, is probably present in several varieties: for many fragments have been seen, and Mr. Morfitt possesses a fine example. These fragments are in a shale which is similar in character to that containing the *angulatæ*.

Coroniceras sauzeanum (d'Orb.) and *Ætomoceras scipionianum* (d'Orb.), in spite of not having been found in place since Tate & Blake's time, are really abundant as excellent casts in a certain very hard dark limestone, of which large, somewhat rectangular boulders are frequently secured, well filled with representatives of these species in various stages of growth.

A glance at the appended list (p. 180) will show many names of the genus *Coroniceras* new to the Yorkshire lists. The same is also true of the *Arnioceras* group.

Coroniceras trigonatum has been well described by A. Hyatt[1]; but his figured types of the species are rather remote from our specimen, which possesses a very massive body-whorl of acutely sagittate section. The grooves shown in the figures are absent from alongside the sharp keel of the Drift example. We have now seen on the coast fragments of four more examples of this bulky ammonite, although it does not appear to be represented in the museums.

Arietites turneri (Sow.), or some near ally, is not infrequent as fragments, but we have not been able to secure a cabinet specimen, not even a fairly complete one. It will be at once called to mind that Sowerby founded this species on a Drift specimen from Norfolk.

Arietites brooki Reynès has occurred more frequently, and consequently some good examples were obtained.

The so-called '*Arnioceras semicostatum*' is so abundant in its various forms that it might be styled 'the Ammonite of the Drift.' It chiefly occurs by the hundred, in cubical blocks of the hard dark limestone so well known in English museums. Although these are always labelled 'from Robin Hood's Bay,' it is suggested that they were really obtained by collectors from Drift material, since neither I nor any one whom I have ever met has found this limestone in place, although it has been much sought for. Again, the museum blocks can easily be matched along the Holderness shore to-day.

Some specimens of this ammonite are found in a shaly matrix; but then they are not so well preserved. The first time that I visited Withernsea for collecting-purposes, there was a really wonderful display of this fossil. There had been a storm associated with a spring-tide, as is very usual on that coast, and apparently a big mass of shaly material had been washed up and scattered, for the beach was literally paved with *semicostatum* slabs for quite 100 yards. Such a display has never been seen since.

The large ammonites of the zone are generally found as mere fragments; yet some excellent examples have been secured by other collectors, and are now housed in the local museums.

[1] 'Genesis of the Arietidæ' Mem. Mus. Comp. Zool. Harvard, vol. xvi (1887–89) No. 3, p. 182 & pl. vi, fig. 3; pl. vii, fig. 1; pl. xii, fig. 15.

Oxynotus Beds.

The derived fossils torn from the *Oxynotus* Zone—applying the term in the inclusive sense, as used by Tate & Blake[1]—represent well all three divisions.

Most of the characteristic forms are found. *Xipheroceras planicosta* occurs in very hard stones, which may only be the ground-down remains of nodules. *Asteroceras obtusum* is generally found in fragments free from matrix, as if from shales similar to those of its bed in Robin Hood's Bay. The same remark applies also to *A. sagittarium.* The spinate examples of Wright's *Xipheroceras planicosta* are also present, but appear to be rare. *Oxynoticeras* is fairly well represented.

On coming, however, to the *raricostatum* division, many hard blackish blocks are found, full of specimens of *Echioceras.* These blocks remind one of the *semicostatum* limestones, and, in consequence of the abundance of examples obtained, the appended list (p. 180) shows comparatively many new forms for Yorkshire. No such limestone is mentioned by Tate & Blake. Simpson's *E. exortum* is merely cited as found in Robin Hood's Bay.

In regard to *Asteroceras acceleratum* Hyatt, a short paper by the present writer appeared in the 'Naturalist' for June 1910.

One most interesting find, early in this search, was a block of tough limestone containing numerous specimens of the young of Blake's *Asteroceras sagittarium* most beautifully preserved. Anyone who has found that ammonite in place at the above celebrated bay knows to his sorrow that such is not the case there. When these small specimens and their matrix were submitted to Mr. Buckman some years ago, he at once suggested the probability of the block having come from the east, and not from the well-known exposure of shales at Robin Hood's Bay.

Altogether, the list shows, for these lowest zones, a much closer resemblance to the ammonite fauna of the South German Lower Lias than any previous one published for Britain.

Seeing that the zones so far enumerated present so many new forms; that the limestones cannot be matched now in Yorkshire; also that they have never been definitely recognized by collectors in that area, although their presence has been assumed, I am forced to the conclusion that, either the sea has destroyed outcrops once exposed of these hard limestones, or the ice plucked them from outcrops in the bed of a former North Sea.

I would urge the latter conclusion.

Armatus-jamesoni Beds.

For some years my colleague and I could not find a single representative ammonite from the *Armatus-jamesoni* Zone, although fragments of the characteristic small belemnites had been found

[1] 'The Yorkshire Lias' 1876, p. 72.

very frequently. However, during the past four years we have been more successful. It has been found, as was to be expected, that scattered examples of the species sought for occur in the cliffs of Holderness. It is well known that large masses of travelled Liassic shale occur in Filey Bay. Now these are from the very beds in question, and have already yielded a few representative trophies. They will probably yield many more when properly worked. I have been informed that the most fossiliferous mass lies far out on the foreshore, and can only be reached at certain states of the tide and beach-material. It has never been my lot to see it exposed; therefore our collection still lacks many of the beautiful pyritic ammonites so characteristic of the zone, and the appended list is consequently at present very weak in representatives of this zone.

Capricornus Beds.

There is little more to be said about the cephalopods of the *Capricornus* Zone than that its characteristic name-fossil is found, as usual, in hard nodules which might very well have been swept from the Yorkshire exposures in the north.

The stout forms of the *Liparoceras-striatum* group, and also examples of the genus *Lytoceras*, which should have their representatives in these beds, appear to be rare in the North Yorkshire Lias. This is also true of the Glacial Drift. I know of only one example of the former group: this I have provisionally entered on the list as *Liparoceras striatum (?)*. This specimen was only noted by me quite recently, during a visit to the Sheffield Museum, where it now is, having been purchased from Mr. Morfitt at Atwick, in Holderness. Again, I know of only one specimen of the genus *Lytoceras* from the Drift: that also was found by the above-named collector.

Margaritatus and *Spinatum* Beds.

Along the shore and in the cliffs there are many shelly boulders, both from the *Margaritatus* Zone and from that of *Paltopleuroceras spinatum*.

Some of these are exceedingly tough, although some are quite brittle, owing to the presence of numerous lamellibranchs. They are good hunting-ground for ammonites, and not infrequently one will yield at least three species. In consequence, we have numerous specimens which have not yet been submitted to Mr. Buckman, and have been entered in the appended list (p. 181) under the local comprehensive terms *margaritatus* and *spinatum*. The boulders from the *Spinatum* Zone are very numerous among the beach-stones. They are also very obvious, because of their coating of yellow or reddish hydrated oxide of iron.

It is interesting to know that *spinatum* boulders are also found in the Drift of Denmark.

Annulatum Beds.

The passage-beds to the Upper Lias or the *Annulatum* Zone have yielded to the ice, so far as is known at present, all the Yorkshire forms, except the rare *Lytoceras cornucopia.*

Spherical or ovoid nodules, yielding many good examples of *Dactylioceras annulatum* or of *Pseudolioceras elegans*, are fairly frequent. Every collector of Yorkshire-Drift fossils soon finds a good example of the former.

Serpentinum Beds.

When one examines the fossils derived from the old *Serpentinum* Zone, one sees many beautiful examples of its grand fauna. The genus *Hildoceras* is well represented by *H. bifrons* Brug., also by kindred forms which pass locally under the same name. I have not yet been able to secure a true *H. serpentinum* Rein. from Yorkshire, but I have found a very near relative in *H. boreale* Seebach. The *falciferi* are also frequently present, and the Drift has yielded two of them new to English lists. The appended list (p. 181) shows an expansion of the genus *Pseudolioceras*, which seems to need a great amount of attention before it becomes thoroughly known. Mr. Buckman informs me that he has found similar examples in the Museum of Practical Geology, Jermyn Street.

Commune Beds.

The zone of *Dactylioceras commune* has also contributed much material to the Drift. Of course, the name-fossil of the zone is found everywhere. I have been able to add very little to the list of recorded species from the zone, although the three predominant genera—*Dactylioceras*, *Cœloceras*, and *Peronoceras*—yield many species to the collector.

Jurense Beds.

From the *Jurense* Beds we have found a few representative species, which do not look so feeble when one considers how small is the Yorkshire list for that zone. It is known, however, that when the zone *in situ* can be properly worked there will be a far larger number to search for in the Drift also.

Liassic Nautili and Belemnites.

The nautili of the Lias are present in the Drift, though rarely, and then are in such a condition that difficulty is experienced in naming them; therefore two only are included in the appended list.

Belemnites are abundant: but, owing to their crystalline structure, those of the Lias are broken up usually into very small pieces; hence the list given here is small.

General Note on the Liassic Fossils.

In regard to the general facies and the matrices of the specimens from all the zones above that of *Oxynoticeras oxynotus*, I am bound to state that they exactly represent what is known to-day of their exposures along the north-eastern coast of Yorkshire. Therefore, they were in all probability swept into Holderness from points not very far distant from the localities where they are obtained *in situ* to-day.

But, as already stated, the material representing some of the lowest zones differs from that of any known exposure on land, and probably indicates localized types of deposit now concealed by the North Sea.

III. Oolitic and Kimeridgian Cephalopoda from the Drift.

Of the Oolitic cephalopoda, I have but a poor account to give. I have so far seen only two specimens from beds below the Oxfordian, and I did not myself find these. They are two examples of *Macrocephalites macrocephalus (?)*, probably from the Cornbrash. No Kellaways specimen has rewarded this search, although that rock is so abundantly supplied with species of ammonites in land-exposures. The scantiness of Oolitic material in the Holderness Drifts has been mentioned by previous workers on the boulders generally, and is thus confirmed.[1]

The Oxford Clay is better represented, and many specimens of *Quenstedtoceras lamberti* (Sow.) have been obtained by the various collectors. The appended list (p. 181) shows five species for the Oxfordian, one of which is new. These are all pyritic, and were found quite free from matrix. The Kimeridgian is represented by much shale with compressed ammonites, which Mr. Buckman has attempted to determine for us. The result is seen in the list given here (p. 182): it will be noticed that most are new records.

Now and then a large piece of a belemnite from the Upper Kimeridgian is found, and one is able to identify it. One large fragment with a deep ventral groove was referred to Mr. G. C. Crick. He has written that it comes nearest to *Belemnites volgensis* d'Orb., which Prof. A. P. Pavlow regards as a synonym for *B. absolutus* Fisch.

IV. Lower Cretaceous Cephalopoda.

Arriving at the Speeton Clays, I am able to say that the yield has been fairly abundant. There are occasionally exposed on the foreshore in Holderness large masses of transported clay, which have been shifted bodily with no damage to the contained fossils. In fact, one may actually find more perfect specimens in them than can be usually obtained at Speeton itself.

The list given here is comparatively long, even though I have not been able to include in it the large globular ammonites of which

[1] See G. W. Lamplugh, 'On the Larger Boulders of Flamborough Head, &c.' Proc. Yorks. Geol. Soc. vol. xi, pt. 2 (1889) Tunstall, p. 234; & *ibid.* pt. 3 (1890) Hornsea, p. 400.

Mr. Morfitt possesses so many well-preserved examples. I have absolutely failed to find these forms described in recent works, although they closely approach *Polyptychites globulosus* of Prof. A. von Kœnen's new work on the Valanginian *Polyptychites*.[1] They are evidently representative of the Valanginian fauna. The mode of preservation of the majority in large nodules of hard clayey limestone differentiates them from anything that can be found at present at Speeton. It is true that specimens akin to them are preserved in the old collections of the museums ; but many of these show evidence of having been rolled by the sea, and have been obtained from the shore, even if they were found at Speeton. This is no reflection on any museum, but it is perhaps a reflection on some of the early collectors.

The belemnites of the Speeton Clays are better preserved than those of the Lias. At Hornsea it is comparatively easy to pick up many good specimens of all the typical species.

V. Upper Cretaceous Cephalopoda.

As yet no ammonites from the Chalk have been found, although, as everyone knows, that rock is plentiful in the Yorkshire Drift.

In consequence of the large amount of Red Chalk scattered in the cliffs everywhere along this coast, its small belemnites have been easily found. The abundant material has no doubt been derived from the extension of the outcrop beneath the present bed of the sea, as the small exposure at Speeton would be quite inadequate to supply it.

The belemnites of the uppermost zone of the English Chalk abound, and everyone who walks along the Holderness shore very soon finds *Belemnitella mucronata*. Besides these plentiful belemnites of the Upper Chalk, collectors obtain a large number of Upper Chalk echinoderms not found *in situ* ; their place of origin is unknown.

These facts afford strong evidence of the former existence of the uppermost zone of the Chalk in the Holderness district, although nothing is present to-day above the *Actinocamax-quadratus* Zone.

VI. Summary and Conclusions.

(1) A large number of ammonites, particularly from the Lower Lias, have been recovered from the Drift. These include many new forms not given in any Yorkshire records hitherto published. They fill up many gaps in the English list when that is compared with the German lists given by Hyatt in Table I of his 'Genealogy of the Arietidæ in the Basin of South Germany.'

(2) There are very few Liassic zones that have not yielded at least one new form.

(3) The matrices of the Lower Liassic fossils are mostly different from those now exposed.

[1] 'Die *Polyptychites*-Arten des Unteren Valanginien' Abhandl. K. Preuss. Geol. Landesanst. n. s. pt. 59 (1909) pp. 19–20 & pl. iv, figs. 1–2.

(4) The fossiliferous boulders from the Middle and Upper Lias exactly resemble the rocks now exposed in North-East Yorkshire.

(5) Oolitic forms are very few in number, except those from the Kimeridgian.

(6) The Speeton Clays have yielded abundant excellent specimens, especially of the Valanginian types.

(7) A much larger outcrop of Red Chalk is indicated than is at present known.

(8) The belemnites of the uppermost zone of the Upper Chalk abound, although they are not found in place in Yorkshire.

Hence one may conclude that:

(α) There were outcrops of the Lower Lias in the track of the ice, that is in the bed of the North Sea of that time, which differed somewhat (both in petrological characters and in the contained fossils) from those now exposed on land. They were probably continuous with the German Basin, for very many forms are common to both. This connexion has been mentioned by various authors before; but I hope that this research has considerably strengthened the evidence given by them.

(β) There were also outcrops of Chalk, higher in its zonal position than any now known in Yorkshire. This latter conclusion has also been arrived at by others.

(γ) The evidence for the connexion of the English Speeton Clays with the Continental deposits of the same age is strengthened by the discoveries in the Drift.

With regard to the identification of the specimens, it will be seen that all the important ammonites on which my conclusions rest have been identified by Mr. Buckman. On myself rests the full responsibility for the remainder.

My best thanks are due to so many, that I refrain from giving the very long list of names. I must, however, especially thank Mr. S. S. Buckman, F.G.S., without whose labours I could have done little more than collect.

All the collectors along these shores and the curators of the local museums have been most generous in allowing full use of their specimens. I am more especially indebted to Mr. William Morfitt, of Atwick; Mr. T. Sheppard, F.G.S.; Mr. G. Sheppard, F.G.S.; Mr. F. Murley; Mr. W. Ennis, B.Sc.; and Mr. J. W. Stather, F.G.S., all of Hull; also to Mr. Miskin, of Hornsea.

Mr. Lamplugh has kindly read through my paper, and has suggested improvements, for which my sincere thanks are due.

Also, I must express my most grateful acknowledgment to the Royal Society for a generous grant towards my travelling expenses, incurred in visiting many museums for the purpose of this paper.

Finally, Mr. H. A. Denham, B.A., my colleague and never-failing companion during very many trips to the coast, deserves a complete and ample acknowledgment for his great share in the work of collecting and in discussing the specimens named.

VII. Lists of Derived Cephalopoda found in the Glacial Drift of Holderness.

Preliminary Note.

The following lists are all arranged in approximate stratigraphical order. They are intended to show what has been found, rather than the exact horizon from which each species has been derived.

With regard to the division of the Lias into Lower, Middle, and Upper, I follow Tate & Blake, for the limits of their divisions of the formation fit in more exactly than any other classification with the results of this research.

All the ammonites marked with an asterisk have been named by Mr. Buckman.

Lower Liassic Ammonites.

**Psiloceras (?) hagenowi* (Dunker-Quenst.).
**Psiloceras* cf. *brevicellatum* Pompeckj.
**Ps. erugatum* (Bean-Phillips).
**Ps. erugatum ?* (Bean-Phillips).
**Ps.* cf. *læve* (Quenst.).
**Ps.* cf. *plicatum* (Quenst.).
**Ps. provinciale ?* (Quenst.).
**Ps.* cf. *psilonotus* (Quenst.).
**Psiloceras* sp. nov.
**Caloceras allasii* (Brown).
**C. belcheri* (Simp.).
C. johnstoni (Sow.).
**C. laquem* (Quenst.).
**C.* cf. *laquem* (Quenst.).
Schlotheimia angulata (Schloth.).
**Schl. exechoptycha* (Wähn.).
**Schl. striata* (Quenst.).
**Schl. trapezoidalis* (Sow.).
**Schl.* aff. *ventricosa* (Sow.).
**Schl.* spp. nov. (2).
Coroniceras gaudryi (Reynès).
**C. gmuendense ?* (Oppel).
**C.* aff. *kridion* (Ziet.).
**C. lyra* Hyatt.
**C. rotator* (Reynès).
**C.* cf. *rotator* (Reynès).
C. rotiforme ? (J. de C. Sow.).
**C. schlœnbachii ?* (Reynès).
**C. spinaries* (Reynès) *non* Quenst.
**C. trigonatum* Hyatt.
Ætomoceras scipionianum (d'Orb.).
Æ. simpsoni (Bean) (in Simpson).
**Agassiceras dal'eræ* (Reynès).
**A. personatum* (Simp.).
A. sauzeanum (d'Orb.).
**A.* aff. *sauzeanum* (d'Orb.).
**A. spinaries* (Quenst.).
**A.* aff. *transformatum* (Simp.).
Microderoceras birchi (Sow.).
**M.* aff. *birchi* (Sow.).
Xipheroceras aureum (Y. & B.).
**X. planicosta* (Sow.).
X. aff. *planicosta* (Sow.).
X. scoresbyi (Simp.).
**Arnioceras cuneiforme* Hyatt.
**A falcaries* Hyatt *non* Quenst.
**A. falcaries* (Quenst.).
**A. geometricum* (Phil.).
**A. hartmanni* (Oppel).
**A. kridioides* Hyatt.
**A. miserabile* (Quenst.).
**A. semicostatum* (Y. & B.).
**A. semicostatum* (Blake).
**Arietites brooki* (Reynès).
**A.* aff. *brooki* (Sow.).
**A. choffati* Pompeckj.
**A.* aff. *collenoti* (d'Orb.).
**A. impendens* (Quenst.) *non* Y. & B.
**A. plotti* (Reynès).
**A.* aff. *turneri* (Sow.).
**Arietites* sp. nov.
Asteroceras acceleratum Hyatt.
A. obtusum (Sow.).
**A. sagittarium* (Blake).
A. stellare (Sow.).
**Vermiceras mandubium* (Reynès).
V. spiratissimum (Quenst.).
Microceras gagateum (Y. & B.).
**Oxynoticeras flavum* (Simp.).
**O.* spp. nov. (2).
**Echioceras costidomus* (Quenst.).
**E. edmundi* (Dum.).
**E. microdiscus* (Quenst.).
**E. robustum* (Quenst.).
**Echioceras* spp. nov. (2).
**Echioceras* sp.
*Cf. *Echioceras neglectum ?* (Simp.).

Middle Liassic Ammonites.

**Deroceras aculeatum* (Simp.).
D. armatum (Sow.).
D. pettos (Quenst.).
**Polymorphites caprarius* (Quenst.).
P. trivialis (Simp.).
Platypleuroceras aureum (Simp.).
**Pl. birchoides* (Quenst.).
Pl. brevispina (Sow.).
Aegoceras capricornus (Schloth.).
Androgynoceras maculatum (Y. & B.).
Liparoceras striatum ? (Rein.).
Lytoceras fimbriatum ? (Sow.).
**Seguenziceras* sp.
Amaltheus depressus (Simp.).
A. ferrugineus (Simp.).
A. lenticularis (Simp.).
A. margaritatus Mont.
**A.* cf. *nodifer* S. Buckm.
**A.* cf. *nodifer* & *depressus* S. Buckm.
Paltopleuroceras elaboratum (Simp.).
P. spinatum (Brug.).
**Paltopleuroceras* sp. nov.
Dactylioceras annulatum (Sow.).
D. athleticum (Simp.).
Pseudolioceras elegans (Y. & B.).
Ps. cf. *elegans* (Y. & B.).

Upper Liassic Ammonites.

Hildoceras bifrons (Brug.).
**H. boreale* (Seebach).
**H.* aff. *boreale* (Seebach).
Harpoceras exaratum (Y. & B.).
H. falciferum (Sow.).
H. mulgravium (Y. & B.).
**H.* sp. nov. (cf. *H. connectens* Haug).
**Harpoceratoides* cf. *alternatus* (Simp.).
**H.* cf. *kisslingi* (Haug).
**H. ovatum* (Y. & B.).
**Pseudolioceras* aff. *dumortieri* S. Buckm.
**Ps. falcidiscus* (Quenst.).
**Ps.* aff. *falcidiscus* (Quenst.).
**Ps. multifoliatum ?* (Simp.).
**Pseudolioceras* spp. nov. (3).
**Canavarella ?* cf. *arenacea* S. Buckm.
Phylloceras heterophyllum (Sow.).
Cœloceras crassescens (Simp.).
C. crassum (Y. & B.).
C. fonticulum (Simp.).
**C. foveatum ?* (Simp.).
**Cœloceras* sp. nov.
**Dactylioceras attenuatum* (Simp.).
**Dactylioceras* cf. *athleticum* & *crassulosum* (Simp.).
D. commune (Sow.).
**D. crassulum* (Simp.).
D. gracile (Simp.).
**D. raquinianum* (d'Orb.).
**D. semicelatum* (Simp.).
**Peronoceras bollense* (Ziet.).
P. fibulatum (Sow.).
P. turriculatum (Simp.).
Porpoceras andræi (Simp.).
**P.* sp. = *fibulatum* (Wright *non* Sow.).
P. perarmatum (Y. & B.).
**P.* aff. *semiarmatum* (Simp.).
P. subarmatum (Y. & B.).
P. cf. *vortex* (Simp.).
**Pseudolioceras compactile* (Simp.).
Ps. gradatum S. Buckm.
**Ps. lectum* (Simp.).
Ps. lythense (Y. & B.).
**Ps.* cf. *lythense* (Y. & B.).
Grammoceras striatulum (Sow.).
Gr. toarcense (d'Orb.).
**Arieticeras* aff. *capillatum* Denck.

Liassic Nautili.

Nautilus striatus Sow.
Nautilus intermedius Sow.

Liassic Belemnites.

Belemnites infundibulum Phil.
B. acutus Miller.
B. charmouthensis Mayer.
B. clavatus Blainv.
Belemnites spadix-ari Simp. (v. *B. clavatus*).
B. vulgaris Y. & B.
B. latisulcatus Phil.
B. subaduncatus Voltz.

Lower Oolitic Ammonites.

Macrocephalites macrocephalus (?) Schloth.

Oxfordian Ammonites.

**Peltoceras athletoides* Lahus.
Quenstedtoceras lamberti (Sow.).
Q. sutherlandæ (d'Orb.).
**Quenstedtoceras vertumnus* (Leck.).
**Quenstedtoceras* sp. nov.

Kimeridgian Ammonites.

**Amœboceras lineatum* (Quenst.).	**Virgatosphinctes ardesicus* (Font.).
**Perisphinctes lacertosus* Dum. & Font.	**Hoplites eudoxus ?* (d'Orb.).
**P. (?) quenstedti* Rouillier.	**H. pseudomutabilis* (de Loriol).
**P. (?) stschurovskii* Michalski.	*Physodoceras lallierianum* (d'Orb.).

Kimeridgian Belemnites.

Belemnites absolutus Pavl.	*Belemnites puzosi* d'Orb.
B. obeliscoides Pavl.	

Speeton-Clay Ammonites.

**Craspedites fragilis* (Traut.).	*Hoplites* cf. *euthymi* (Pict.).
Polyptychites beani Pavl.	*H. regalis* (Bean).
P. bidichotomus (Leym.).	*H. oxygonius* Neum. & Uhl.
P. gravesiformis Pavl.	*Simbirskites concinnus* (Phil.).
**P. keyserlingi* (Neum. & Uhl.).	*S. speetonensis* (Y. & B.).
P. lamplughi Pavl.	*S.* aff. *discofalcatus* (Lahus).
Hoplites amblygonius Neum. & Uhl.	**Neocomites* aff. *deshayesi* (Leym.).
**H.* cf. *amblygonius* Neum. & Uhl.	

Speeton-Clay Belemnites.

Belemnites explanatus Phil.	*Belemnites jaculum* Phil.
B. lateralis Phil.	*B. brunsvicensis* Stromb.
B. subquadratus Rœm.	

Chalk Belemnites.

Belemnites attenuatus Sow.	*Actinocamax quadratus* Blainv.
B. minimus List.	*Belemnitella lanceolata (?)* Schloth.
B. ultimus d'Orb.	*B. mucronata* Schloth.

Discussion.

Mr. G. Barrow drew attention to the well-known evidence, at Blea Wyke (Robin Hood's Bay), of a sudden deepening of the water at the time when the highest beds of the Lias and the lowest of the Oolites were deposited. If this continued eastwards, it would naturally explain why the matrix of some of the fossils exhibited by the Author differed from that seen on the coast at Robin Hood's Bay. Farther north, the Liassic material brought inland in the Glacial deposits did not appreciably differ from that met with *in situ*.

Mr. G. W. Lamplugh congratulated the Author on having vindicated the aspersed reputation of the transported fossils of the Drift, which had suffered unduly from unscrupulous usage by a few of the early collectors. These fossils were of particular value when, as in the present case, they carried an indication of the stratigraphy of the inaccessible sea-bottom. In Holderness the ice had served as a dredge working landward, and its tip-heaps were left ready for inspection in the sea-cliffs. The results achieved by the Author from his study of the derived cephalopoda alone showed how much we might learn respecting the seaward prolongation of

the strata, if these researches were extended over the whole of the transported fossils. The speaker strongly hoped that the Author and his colleagues would continue the work so excellently begun.

Mr. R. S. Herries said that he had listened to the paper with much interest. He did not know the Holderness Drifts, but had collected many specimens from Filey Bay. The blocks containing *Ammonites semicostatus*, found on the *Bucklandi* reefs in Robin Hood's Bay, he believed to have been washed up from reefs farther out to sea. The comparative scarcity of Oolitic ammonites in the drifts was accounted for by their being poorly represented in the Yorkshire Oolites, except the Kellaways Rock which was a friable deposit not easily preserved.

The Author, in briefly replying, thanked the Fellows for the reception given to his paper. In answering Mr. Herries's remarks, he stated that there was still no evidence that blocks with *Ammonites semicostatus* had ever been found *in situ* in Robin Hood's Bay.

11. *On a* Mass *of* Anhydrite *in the* Magnesian Limestone *at* Hartlepool, *and on the* Permian *of* South-Eastern Durham. By Charles Taylor Trechmann, B.Sc. (Communicated by Prof. E. J. Garwood, M.A., V.P.G.S. Read January 8th, 1913.)

[Plate XXII—Map.]

Contents.

I. Introduction.

The exposures of Magnesian Limestone in the area under discussion in the present communication are indicated on the 1-inch Geological Survey [Drift] Map, Sheet 103 N.E. (New Series, Sheet 27), with the exception of the fine continuous sections of Castle-Eden, Hardwick, and Hesleden Denes: these are only indicated in part, and seem to have been overlooked by the surveyors. No attempt is made to distinguish the divisions of the Magnesian Limestone. Otherwise I know of no paper dealing with the district as a whole, though scattered references to the exposures of the coast-section and Castle-Eden Dene occur in various publications.

The isolated outcrops of Upper Magnesian Limestone with their associated anhydrite-mass, on which the two towns of Hartlepool and West Hartlepool are built, are bounded on the west and north-west by a valley filled with Glacial and superficial débris, probably connected with the watershed of the pre-Glacial Tees Valley. The nearest outcrops of Magnesian Limestone occur nearly 2 miles away to the west, and nearly 3 miles away to the north-west along the coast.

The area is bounded on the south-east by the fault, everywhere hidden and therefore largely problematical, which brings the Red Beds down against the Magnesian Limestone, and is marked on the

Survey maps as extending in a straight line from West Hartlepool to a point south of Darlington. The levels of the limestone in borings north and south of this fault at West Hartlepool show a difference of about 700 feet, and so the southward throw of the fault is probably of this magnitude. Its exact point of contact with the sea-coast would seem to be where the road from Seaton Carew to West Hartlepool crosses the railway near the saw-mills and engine-shed.

The Red Beds, well exposed at Long Scar and Seaton Carew, are not touched upon in this paper, except as the protective covering of the underlying Magnesian Limestone.

To the west and north-west the typical sections of Magnesian Limestone on the coast and in the various ravines and isolated outcrops are described as far north as Castle-Eden Dene, and as far west as the limit of the Magnesian Limestone in that dene.

The whole south-western portion of the area is hidden by Glacial drift, and does not concern this paper. Glacial action has brought about an intense deformation of the limestone in parts; this is especially noticeable in some of the Upper Limestones of the coast-section, and makes a detailed mapping of the coast an almost impossible task. The effect seems, however, to be a comparatively superficial one.

As may be supposed, on account of the internal collapse of parts of the Magnesian Limestone, the dip of the beds is a very variable one; but the prevailing dip is a few degrees eastwards or south-eastwards, corresponding to the general slope of the country towards the sea.

The work on the outcrops and sections in the area is based chiefly on palæontological evidence.

II. The Mass of Anhydrite in the Magnesian Limestone at Hartlepool.

The observations here detailed deal primarily with a large mass of anhydrite and the associated gypsum, which is proved by a boring and other indications to occur in close proximity to the Upper Magnesian Limestone upon which the towns of Hartlepool and West Hartlepool are built. To the subsequent denudation and erosion of this mass the harbour of Hartlepool owes its existence.

Had the Magnesian Limestone extended without an interruption from its occurrence on Hartlepool foreshore to its second outcrop at the gasworks at West Hartlepool, it is clear that the intervening 'slack' or valley which accommodates the harbours of the two towns could not have existed under the given conditions. Thus the harbour of Hartlepool, situated as it is in a somewhat anomalous and unexpected position on the coast, proves to be in respect to its mode of origin in many ways a very interesting and unusual phenomenon.

The presence of gypsum in the harbour might have been inferred without the evidence of any boring, from the fact that masses of

that material often of very large size, reaching several hundredweight, have frequently been observed in the Boulder Clay filling the 'slack,' and are constantly brought up by the harbour-dredger from the depression occupying the area between the two outcrops of Magnesian Limestone, and also from the bed of the sea out towards the bay. Their extension northwards and westwards is strictly limited to the area of the Hartlepool slack, but eastwards and south-eastwards their distribution is uncertain; though I have been informed, on not very sure authority, that they extend across the mouth of the Tees and have occurred as far south as Redcar.

These masses of gypsum seem to be true glacial boulders, torn up by a glacier passing in a south-easterly direction from the then exposed surface of gypsum, and embedded in the Boulder Clay. Before the coast was so largely encroached on by buildings, they seem to have been exposed in several places, where the material was largely quarried for carving small ornamental objects.

The boulders are variable in colour, generally white but often red, pink, or brown, and all seem to be pure gypsum without anhydrite or limestone.

The promontory upon which Hartlepool is built is an isolated outcrop of Upper Magnesian Limestone, and is roughly oval in its present outline, lying with its longer axis oriented north-westwards and south-eastwards, measuring about half a mile in width and rather over a mile in length, from its first appearance at Parton Rocks on the north-west to its disappearance beneath the sea on the south-east near the end of the new breakwater.

About five-sixths of a mile west of the exposure the Upper Magnesian Limestone is again seen well exposed in the railway-cutting near the gasworks at West Hartlepool; and it is further observable, skirting the harbour for a distance of nearly a mile.

The intervening slack is filled in with Boulder Clay, upon which rests a submerged forest or peat-bed, overlain in part by blown sand and superficial deposits. In these Glacial and recent beds the various harbours and timber-ponds of the two towns have been excavated and constructed at different times.

The first solid rock met with on piercing this covering of superficial deposits is a bed of anhydrite of great thickness, which is found to be altered to gypsum on both its upper and nether surfaces.

Unfortunately, but one boring is available showing the true thickness of this bed, so our knowledge regarding its lateral extension and thickness in other directions can be inferred only.

There was nothing to indicate that the strata passed through were in other than a horizontal position. If the uniform 'slack' or depression in which the harbours are constructed is entirely due, as seems beyond question, to the erosion of the anhydrite, then the mass should have an oblong or elliptical outline with its longer axis lying north-west and south-east, and measuring possibly a mile and a half in length and nearly a mile in width.

The boring in question was sunk in 1888 by J. Vivian & Co., of Whitehaven, by the diamond-boring process giving 6-inch cores,

at the Warren Cement-Works at Hartlepool, at a spot exactly a sixth of a mile from the nearest known outcrop of Magnesian Limestone which occurs beneath the iron railway-bridge at Throston, and on the north-west or inner side of the outcrop of that rock upon which Hartlepool stands.

The following section was passed through in descending order:—

	Feet		Thickness in feet	inches.
Blown sand			22	0
Submerged forest- or peat-bed			8	0
Red clay	18	Glacial deposits.	67	0
Red clay with small stones	6			
Dark clay and stones	39			
Red clay	2			
Soft limestone (or boulder)	1			
Red clay	1			
Gypsum			1	5
Anhydrite			265	7
Dark-grey limestone passing into a broken limestone with abundance of water.			38	0

The solid rock was met with at a depth of 97 feet, and consisted of gypsum, passing after a further depth of 17 inches into a bed of pure anhydrite of the unusual thickness of 265 feet 7 inches.

The anhydrite was more or less streaked and banded with Magnesian Limestone in its lower part, the bands of limestone occurring in irregular horizontal fragments and layers, which become larger and more numerous towards the base. The anhydrite was again partly altered to gypsum at the base of the mass, and passed quite conformably down into a bed of very hard dark-grey Magnesian Limestone, which was met with at a depth of 364 feet and pierced to a depth of 38 feet, when a bed of broken rock was met with and a good feed of water was obtained; this water proved to be highly charged with solids, chiefly chlorides and sulphates.

I recently undertook a detailed examination of the cores of the boring which are still preserved, with the view of determining, if possible, the exact horizon of this limestone, its composition, and the nature of its residues. Although the rock had long been supposed to be unfossiliferous, by carefully breaking it up three recognizable species of fossils were obtained.

The cores of the limestone are now very much mixed up, but in the 38 feet of gypsiferous rock underlying the anhydrite-bed at least three varieties are met with, as follows (in their apparent order of superposition):—

A. Limestone interbedded with anhydrite towards the lower margin of the anhydrite-bed. A hard, compact, dense, dark-grey rock, containing much anhydrite but no gypsum.	No fossils.
B. Immediately underlying the anhydrite-bed. A very hard, dark-grey, dense, fine-grained limestone having fissures and cracks filled with gypsum. The rock is brecciated in part, the broken fragments being re-cemented with gypsum.	No fossils.

C. Tough, coarse-grained, highly gypsiferous limestone, darker in colour than B. The gypsum occurs in cracks and fissures, and is also largely incorporated with the mass of the rock.	*Strophalosia lamellosa* Gein.; in poor preservation, but clearly recognizable.[1]
D. A very dark, highly crystalline, but friable and porous limestone, much broken up in parts. This is the broken limestone whence the water was obtained.	*Epithyris elongata* Schl. & *Bakevellia ceratophaga* Schl.; both fairly numerous.

[1] I have since detected traces of bryozoa, and a small obscure gasteropod in this bed.

The following analyses of the four samples were made, excluding the gypsum and anhydrite, so far as it was possible to remove these substances by hand before analysis:—

	A.	*A.*[1]	*B.*	*C.*	*D.*
Insoluble residue[2]	2·03	2·78	0·27–1·00	0·82	0·62
Water, organic matter, etc.	trace	trace	trace	3·17	2·29
Al_2O_3, P_2O_5	trace	trace	0·15	trace	0·20
FeO	0·61	0·83	1·56	1·06	5·37
$CaCO_3$	38·16	52·36	56·00	42·86	56·39
$MgCO_3$	32·80	45·01	42·79	33·92	34·97
$CaSO_4$	27·40	—	0·18	19·04	1·17

[1] Calculated without the anhydrite which is disseminated through the rock.

[2] The insoluble residue of all these samples is very much alike, and offers the following peculiarities:—

(1) Comparatively large quartz-grains: some with idiomorphic outlines, others irregular, and both full of inclusions. The inclusions consist of crystals and crystal-aggregates and groups of pyrite, showing the cube, octahedron, and pentagonal dodecahedron, mostly in combination one with the other. The idiomorphic quartz-grains show clear margins, where the perfect crystal has subsequently grown round a normal irregular grain with pyrite inclusions.

(2) Free pyrite in aggregates and free crystals of the above-mentioned forms and combinations.

(3) Highly refractive grains resembling zircons with rounded angles.

(4) Dichroic minerals resembling tourmaline in occasional crystals.

Only in one limestone at the surface (concretionary series) have I yet seen residues of quartz enclosing pyrite.

The limestones obtained in this boring are unlike any member of the series exposed at the surface. Their dark colour is largely due to organic oily matter, but more especially to impure unoxidized iron salts chiefly present as ferrous carbonate. The highly magnesian character of all of them will be noticed, a feature indicating the original state of deposit of the formation.

Sample A, the rock interbedded with the anhydrite, is assumed, I think safely, to be a limestone, if not in the condition of deposition, at least with its constituent elements present in the proportions in which they were originally deposited. These samples are completely enclosed or encased in the bed of impervious anhydrite. The rock is hard, dense, and compact, recalling in this respect any normal Carboniferous or other limestone. It is entirely unbrecciated and undisturbed. It contains a large quantity of anhydrite but no trace of gypsum, the anhydrite being arranged in parts in plates and aggregates of tabular formless crystals throughout the rock, recalling, as will be shown, in appearance the hollow negative

pseudomorphic aggregates found in several beds of Magnesian Limestone at the surface.

The gypsiferous limestones underlying the anhydrite represent an intermediate stage between the above-described rock and the completely gypsum-free rock as it is exposed at the surface. They are in a condition comparable with the limestones underlying the Red Beds south of the West Hartlepool fault, and in other areas where the Magnesian Limestone has been partly protected. Removal of the protective covering, and exposure to atmospheric agencies, with consequent leaching-out of the gypsum and oxidation of the ferrous compounds, would bring about a complete change in the nature and appearance of these rocks. If accompanied by pressure of overlying strata, the consequent collapse and degradation of a bed, such as D, would probably complete the obliteration of the already scanty traces of organic remains.

The anhydrite cores have now been lying in the open air for 24 years, and are considerably weathered and pitted, the mineral first becoming changed to gypsum and then dissolved away. *In situ,* however, the hydration seems to take place much more rapidly than the solution of the gypsum. The result is that at the base the anhydrite mass was found more or less completely changed to gypsum for 4 or 5 feet.

Both in this part, and in the underlying gypsiferous limestones, some instructive features which seem to throw light on the present condition of the formation were observed. They can be well observed if the specimens are left under running water for some days, in order to remove the superfluous gypsum. The following may be mentioned:—

(1) Fragments from the lower part of the anhydrite-bed enclosing streaks of Magnesian Limestone. The anhydrite is almost completely changed to gypsum throughout its mass. On the weathered surfaces glistening crystals of anhydrite are seen in layers or irregular masses standing out from the more rapidly dissolving gypsum, while the Magnesian Limestone is becoming liberated in soft, friable fragments taking on in part a yellow powdery character, very different in appearance from the streaks of rock in the undisturbed anhydrite above. If left in water the mass disintegrates, throwing down the fragmentary Magnesian Limestone. The complete removal of sulphates from a thick bed such as this suggests an origin for some of the irregular masses of soft comminuted breccia which are seen at various horizons in the Magnesian Limestone.

(2) Masses of brecciated limestone recemented with gypsum. The brecciation of the Magnesian Limestone evidently begins before the complete removal of gypsum, and before the rock is chemically altered, no doubt through the strains set up in the mass of the formation. The hard, brittle, unfossiliferous rock (B) is found in part very much broken up into angular fragments of all sizes down to extremely minute powdery particles. The fragments are more or less displaced vertically and are slightly separated, the intervening spaces being occupied by secondary gypsum cementing the otherwise undisturbed brecciated fragments. After having been placed under running water for some time the mass becomes disintegrated.

(3) Brecciated fragments of hard brown limestone associated with gypsum. Aggregates of dolomite crystals are seen on the surfaces of the fragments as the gypsum is dissolved away, and also lying loose in the secondary gypsum.

Some details of the Warren Cement-Works boring were published in connexion with a paper dealing with the salt-beds of South-Eastern Durham, read before the Manchester Geological Society on June 5th, 1888.[1] Mr. Bird remarks upon the abnormal thickness of the anhydrite in this boring, and says:

'This may probably be the Lower Anhydrite of the Saliferous Beds, although the one foot of limestone above it is rather against the theory.' (*Op. cit.* p. 575.)

There seems to be no doubt that the limestone was merely a boulder near the base of the Glacial Clay.

I was for a long time of the opinion, which seems to have been the opinion of the borers also, that this anhydrite was an abnormal thickening of the Lower Anhydrite Series directly underlying the salt-beds, and supposed that its presence might be explained by the existence of a trough-fault having a north-westerly and south-easterly direction, and bringing that series down against the Upper Magnesian Limestone.

Several facts, indeed, seemed to favour this view, which it is not necessary to recapitulate here; and, before the palæontological evidence furnished by the underlying limestones was forthcoming, the probabilities were about equally divided between the fault and the inclusion theories.

Against the fault theory, the following reasons may be cited, which were kindly suggested to me by Prof. G. A. Lebour:—

(i) No bed of anhydrite or gypsum approaching a thickness of 265 feet is met with in the Red Beds overlying the Magnesian Limestone in Durham or North Yorkshire. I find that the greatest recorded thickness of the true Lower Anhydrite of the Saliferous Series is 77 feet 6 inches at the West Hartlepool Cement-Works of Messrs. Casebourne; while in the Seaton-Carew boring it was only 38 feet 7 inches thick. Taking into account the whole of the anhydrite-beds met with in these two borings: that is, the upper layer which is always met with overlying and protecting the salt, and the lower series of more variable thickness underlying the salt, together with a bed of red marl, presumably representing the salt absent here, the total thickness was 124 feet 6 inches at West Hartlepool and 54 feet 7 inches at Seaton Carew.

(ii) Among all widely-developed dolomitic rocks abroad, layers or lenticles of gypsum or anhydrite, regular or irregular, and often of very great size and thickness, are common at many horizons, and by their solution and erosion have been repeatedly shown to be the cause of much internal deformation of the enclosing limestone, as well as of many 'slacks' and valleys at the surface. The phenomenon is very usual in connexion with the Trias in many parts of the Alps, where it has been called in to explain the features of certain high-level lakelets and valleys. So far as physical and chemical characteristics are concerned, the Triassic Alpine Dolomites are in many ways comparable with the Durham Permian Magnesian Limestones.

However, the presence of two genera of brachiopoda in the limestone underlying the anhydrite at Hartlepool must allocate it to some bed of the great middle fossiliferous division of the Magnesian

[1] W. J. Bird, Trans. Manchester Geol. Soc. vol. xix (1888) p. 564.

Limestone. The experience of all workers in this formation in Durham is that brachiopods die out and disappear before the deposition of any of the upper beds.[1]

We are, therefore, driven to the conclusion that the greater part of the Upper Magnesian Limestone Series, and apparently also a considerable portion of the middle beds, are here represented and replaced by an included mass of anhydrite of uncertain shape and size, occupying in its present condition a strictly limited area in the Hartlepool district.

Fig. 1 (p. 192) is an attempt to represent diagrammatically the boring through the anhydrite, and side by side with it the most reliable boring records obtainable in the immediate vicinity, with the view of showing the beds which are replaced by the anhydrite.

The discrepancy in the limestone in the various borings will be noticed, and, indeed, the absence of any bed having anything like a stratigraphical continuity over an extended area is a marked feature of the Upper Magnesian Limestones in Durham.

The boring near Hart Railway-Station is $2\frac{1}{4}$ miles north-west of the Warren Cement-Works boring. The limestone was met with at 37 feet below the surface and completely pierced. It had a thickness of 708 feet, from which fact and the outcropping of Upper Limestones not far away, one may reasonably infer that all the great divisions are represented. No fossils were recorded, and the cores are now lost.

The boring at Howbeck is situated near the Hartlepool Union Workhouse, about a mile away from the anhydrite boring. The boring was still in limestone at 324 feet, and a good supply of water was obtained.

At West Hartlepool Waterworks, whenever borings are sunk, a good supply of water is obtained, and constitutes the household water of the two towns. It has been supposed, though it is by no means certain, that the water is held up by the mass of impervious anhydrite a little to the eastward.

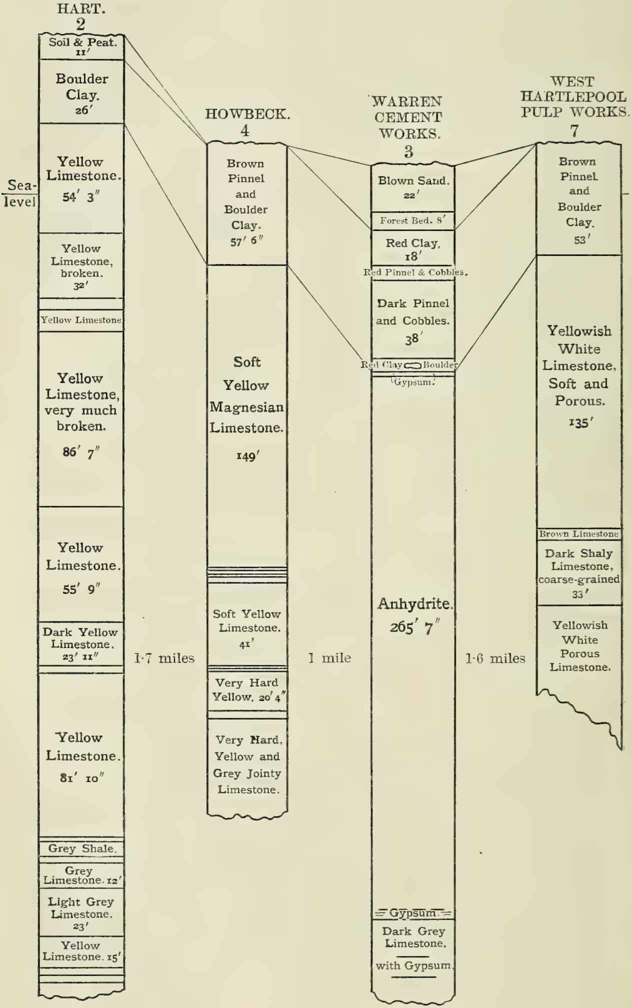
South of the West Hartlepool fault a boring was sunk at the West Hartlepool Cement-Works (Casebourne's Boring). Under 30 feet of Glacial drift the red beds were encountered, having a thickness of 575 feet 6 inches, following which the Upper Anhydrite Series (18 feet 6 inches), red and blue marls representing the here-absent salt-bed (28 feet 6 inches), and the Lower Anhydrite Series (77 feet 6 inches thick), occur in descending order.

Beneath this, the Magnesian Limestone with gypsum was met with at a depth of 730 feet from the surface, and was pierced to a depth of 40 feet, the total depth of the boring being 770 feet.

The boring was not continued far enough into the limestone to show whether any extensive bed of anhydrite existed in it, and the cores having, by a great misfortune, been recently thrown into a pond and buried up, I was unable to examine them for fossils.

[1] This feature seems to be common to the Upper Limestones over the whole of North-Western Europe.

Fig. 1.—*Vertical sections of borings in the Hartlepool area.*



III. Borings in the Magnesian Limestone where it is protected by Red Beds.

The great boring at Seaton Carew was described in detail by E. Wilson,[1] who stated that no fossils were detected in the cores, so that no opinion can be formed as to the horizon of the limestones met with. The limestone here occurs nearly 200 feet higher up than at West Hartlepool Cement-Works, and probably has a northward dip. The section is important in connexion with the present paper, as revealing a mass of 'anhydrite with beds of dark-blue shale and gypsum,' 35 feet thick, at a depth of 84 feet from the top of the Magnesian Limestone, which here attains the greatest recorded thickness of 878 feet. It is noteworthy that the limestone is gypsiferous throughout this great thickness.

A critical examination of this boring, so far as the details recorded may be reliable, shows the aggregate proportions of the formation to be as follows:—

	Feet.
Sulphate-free limestone	480
Limestone impregnated with gypsum and anhydrite	358
Pure anhydrite and gypsum	35

At 140 feet from the bottom of the limestone is a thickness of 260 feet of limestone free from gypsum, which might correspond to part of the Shell-Limestone, but no fossils are recorded. I have very little doubt that they would have been found, if a search had been made.

With this boring another may be contrasted: namely, that sunk at Whitehouse Farm near Norton in 1892,[2] about 7 miles south-west of the Seaton-Carew boring, where the thinnest recorded complete section of the Magnesian Limestone occurred, measuring only 299 feet in thickness. No fossils are recorded. Whichever division of the formation may be represented by this rock, the fact of importance in connexion with this discussion is the presence of large interstratified beds of anhydrite and gypsum, having an aggregate thickness of 84 feet. They commence about 85 feet from the top of the Magnesian Limestone, the most considerable individual bed being 37 feet thick. The sulphate-free rock in this boring has an aggregate thickness of about 160 feet, while the beds of limestone impregnated with anhydrite and gypsum aggregate about 56 feet.

The presence of large quantities of anhydrite and gypsum in the Magnesian Limestone is a usual feature wherever that formation is covered by a protective layer of comparatively impervious material as in South Durham, and undoubtedly represents a more original and unaltered condition of the formation.

This fact encourages the idea that the mass of anhydrite beneath

[1] Q. J. G. S. vol. xliv (1888) p. 781.
[2] T. Tate, *ibid.* vol. xlviii (1892) p. 488.

Hartlepool Harbour occupied laterally a very much more extended area when it was originally deposited; also that it has been gradually reduced in size, and represents in fact the last remnant of anhydrite formerly common to the whole formation, its great size and thickness having saved it from complete removal.

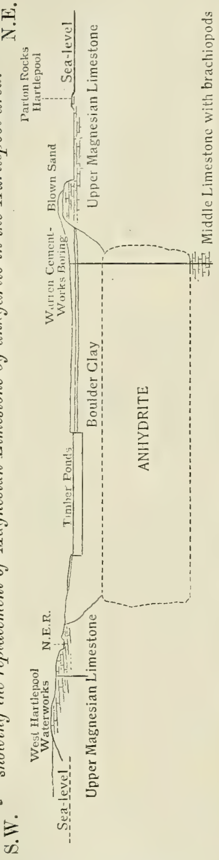


Fig. 2.—*Section from the sea-coast at Throston, Hartlepool to West Hartlepool Waterworks, showing the replacement of Magnesian Limestone by anhydrite in the Hartlepool area.*

[Horizontal scale: 3 inches = 1 mile; vertical scale = 4 times the horizontal.]

One of the objects of this paper is to demonstrate that most of the changes and vicissitudes undergone by the Magnesian Limestone are due to the subsequent removal of sulphates from the formation. These sulphates were originally present, both as interstratified beds and lenticles, and also impregnating and in very close association with the limestone, and their removal brought about a collapse, degradation, and settling-down of great parts of the formation.

The most obvious result of this process is the brecciation and internal deformation which are such common features of the rock. The less obvious changes are those resulting from the removal of sulphates closely incorporated with the mass of the rock, leading to a molecular degradation with consequent segregation, and other processes which bring about a more or less complete obliteration of the fossils.

The solution-breccias described in the present paper frequently simulate effects which might have been anticipated if the Permian rocks had been subjected to horizontally-acting dynamic forces. While not presuming to deny the possible existence of such forces, I have seen nothing in the southern part of Durham which would lead me to suppose that the disturbances in the Magnesian Limestone were due to causes other than the effects of solution herein described.

The brecciation is confined to the Magnesian Limestone. In

Blackhall Sinking the thin bed of Marl-Slate together with the Yellow Sands were to all appearances undisturbed and in normal condition, in striking contrast with the great mass of deformed carbonates lying above.

Slickensided surfaces have been noticed in several instances. They occur between the masses of Shell-Limestone conglomerate at Blackhall Rocks, and can be seen on a small scale in the brecciated gypsiferous limestone beneath the anhydrite-mass at Hartlepool, where the gypsum seems to have acted as a lubricant; but these instances are purely local, and are such as might have been produced by movements set up in the mass of the rock through reduction in volume by solution.

Whether the more extended movements which have recently been described[1] from the Sunderland area are due to the same or to independent causes must be left as an open question for the present.

The discrepancy between the thickness of the protected limestone at Seaton Carew (878 feet) and that of typical sections of the unprotected formation north of the fault which include all the divisions (Blackhall Sinking—688 feet, Hart Boring—708 feet), would seem to point to a very considerable reduction in volume on removal of the sulphates; though it would appear to be necessary to hold this view with reserve, owing to the possibility of the fault having been active in Permian times.

IV. The Former Presence of Soluble Constituents in the Magnesian Limestone.

The former presence of soluble constituents, presumably sulphates, can be inferred from several features observable in the formation in this and other areas.

(1) The intense porosity of many beds, both in the Upper and in the Middle Limestones, which, from the existence of plentiful casts of fossils, are shown to be practically unaltered in volume. The highly magnesian character of these beds further indicates their original condition.

(2) The presence of hollow or negative cavities or spaces left by crystals or aggregates of crystalline material in many beds. They are most apparent in the well-stratified, unfossiliferous beds of the middle division, overlying, or otherwise associated with, the Upper Shell-Limestones; but I have also found them sparsely distributed in some of the fossiliferous beds. When very numerous, causing the rock to become extremely porous, they lead in some cases to a structural collapse with development of the usual hard, calcareous, segregated breccias. When replaced by calcite, the crystalline aggregates appear as stellate structures on broken surfaces.

[1] D. Woolacott, 'Stratigraphy & Tectonics of the Permian of Durham (Northern Area)' Q. J. G. S. vol. lxvii (1911) pp. 312–13.

In some thinly-bedded limestones they are arranged in layers on the planes of bedding, as though some crystalline substance had been thrown down rapidly from a concentrating solution as formless plates and aggregates on the sea-bed, to become covered up by the next layer of sediment, and only to be removed again by solution long after the solidification of the deposit. I find that the rock which encloses these structures is always of a highly magnesian character (45 per cent. of magnesium carbonate).

These structures can be compared with crystals of anhydrite that occur in several pieces of unaltered Magnesian Limestone in the lower part of the anhydrite-bed at Hartlepool. In this case the pieces have been cut through by the boring-tool, giving a surface which has been exposed to the atmosphere for 24 years. The anhydrite has been changed to gypsum and dissolved away, the result being a fretted surface of limestone with stellate spaces similar to, but generally on a smaller scale than, those in the Magnesian Limestone at the outcrops.

Stellar aggregates of gypsum are seen in masses of that material dredged from Hartlepool Harbour. They are obscure structures, and may be pseudomorphic after anhydrite.

J. W. Kirkby[1] refers to the pitted surface of several of the limestones of the Brotherton Beds and small-grained dolomites of South Yorkshire, which seems to be an analogous structure; and makes some remarks upon the curious false bedding of parts of the Magnesian Limestone. He doubtfully refers the former structures to

'some peculiar concretionary action, analogous to that which gave the Upper Limestone of Durham its remarkable structures.' (*Op. cit.* p. 291.)

(3) The apparent former presence of lenticular inclusions of soluble substance. This is well seen in some of the thinly-bedded limestones of the Upper Middle Division, exposed on the shore south of Blackhall Rocks. In the cliff-section, the strata present a series of undulations, and are very loosely compacted along the planes of bedding. On the foreshore, however, the beds are seen in the form of low irregular domes[2] of more or less circular outline, measuring as much as 10 feet in diameter. Several examples are broken into by the sea, and present every appearance of having enclosed a lenticular mass of some easily-removed material, either powdery limestone or some soluble constituent. J. W. Kirkby[3] notices that in the flaggy limestones of the Brotherton Beds of South Yorkshire 'the surface-planes are generally a little apart.'

Whether the sulphates in the Magnesian Limestone were originally all deposited as anhydrite, or partly as gypsum, is not precisely an easy question to decide. The evidence seems to be in favour of complete anhydrite deposition, such as might be expected in a sea charged with magnesian salts.

[1] Q. J. G. S. vol. xvii (1861) p. 290.

[2] This feature was first noticed by my friend, Mr. G. T. McKay, M.Sc.

[3] *Op. jam cit.* pp. 289–90.

The Hartlepool boring shows that hydration takes place more rapidly than solution of the gypsum, and therefore the expansion following upon the hydration of the anhydrite might cause much of the very curious internal deformation and crumpling on a small scale seen in many of the thinly-bedded limestones; this would probably be followed by a collapse and movement in the opposite direction on solution of the gypsum.

All the samples of normal 'unprotected' Magnesian Limestone that I have analysed contain a small quantity of sulphur; but in no case does it exceed 0·2 per cent. of sulphur trioxide within my experience, nor have I yet determined its state of combination in the rock.

The changes consequent upon the unstable solubility-equilibrium of dolomitic carbonates are very apparent in certain beds of the Magnesian Limestone. There can be no doubt that the intensely porous condition in which many of the beds are left after removal of the sulphates lays them open to these changes; a fact which should never be ignored in studying the endless forms of segregation and brecciation that this formation affords.

The changes may be conveniently indicated by the following synopsis:—

Calcareous Constituent.	Original Rock.	Magnesian Constituent.
Hard, skeletal, spongy, calcareous structures, ultimately coalescing into beds of dull, lustreless, crystalline, massive rock of saccharoidal structure and all shades of colour, (white, brown, bright yellow, ashen-grey, etc.). Magnesium carbonate 0 to 10 per cent. Fossils always obliterated.	Normal, bedded, fine-grained limestones or 'roestones.' Often intensely porous and friable. Magnesium carbonate 40 to 45 per cent. Fossils traceable if originally present.	Yellow powdery material,[1] present as irregular lenticles or pockets. Frequently containing dusty cavities or calcite-lined geodes. (Contraction effects?) Magnesium carbonate approaching 45 per cent. Fossils obliterated in the final state.

The powdery magnesian constituent occurs in all stages of association with, or complete rejection by, the calcareous segregations, the result being an endless variation both in appearance and in composition of the rock-mass.

In all fossiliferous sections it can be observed that, in proportion as the segregation of calcareous structures becomes more apparent, the obliteration of the fossils becomes more complete.

The beds chiefly thus altered prove to be the eastern and western equivalents of the Shell-Limestone, together with certain beds of the Upper Limestones—that is, limestones which on other considerations are shown to have been originally rich in sulphates.

The Shell-Limestone, for reasons indicated in § V of this paper, is very much less affected; but the change is by no means absent, especially in the upper beds of that division.

Siliceous residues are generally identical in character in the various stages of such altered rocks, though I have frequently

[1] Generally described as 'marl' or 'marly limestones,' a too-often repeated error.

found them less concentrated in the calcareous segregations, with subsequent idiomorphic growths round the quartz-grains.

Patches or beds of original unsegregated rock occur in several sections of these highly-altered rocks, frequently of very limited extent and irregular shape. As already stated, they are generally of an intensely porous and friable nature and considerably fractured. The fossils are obtained only by carefully breaking the fragments along the original bedding-planes. These unaltered parts of the formation afford a useful clue to the original nature and palæontological horizon of several highly-altered limestones.[1]

The above-described segregation is quite distinct from the typical concretionary structure of the lower beds of the Upper Limestones. Both the botryoidal bodies and their investing matrix yield a great quantity of oily and carbonaceous matter on solution in acid: a feature not so evident in the former segregations, and one which would seem to suggest the formation of these bodies under the influence of organic matter.

From analogies in quantity of organic matter, nature of residues, and general preservation of fossils, I am inclined to attribute the 'cannon-ball' structures to the action of segregation at a very much earlier period of the formation, anterior to the great changes undergone by the rock.

The action of percolating water in leaching out the soluble constituents originally deposited with the Magnesian Limestone has already been noticed. The part which it plays in the dedolomitization of great tracts of the formation through the removal, in great part mechanical, of the powdery magnesian constituent has also been touched upon.

The Upper Shell-Limestones are in places considerably altered by the action of water, which percolates with particular ease through these rocks. In Blackhall Colliery Sinking, at one time in 1911, as much as 15,000 gallons per minute were being pumped from the Shell-Limestones. Analysis of this water showed it to correspond to sea-water diluted to about five times its volume with water containing calcium carbonate in solution. Previous analyses had shown that the proportion of sea-water varied at different levels.

The effect is very noticeable in the so-called 'interbedded conglomerate' of Howse, which seems to occupy a fairly definite horizon in the Upper Shell-Limestones. The rounded fragments are interbedded among layers of bedded limestone, and appear to have formed the hard unaltered cores in a soft and friable mass of limestone undergoing gradual change, the soft powdery portion having been removed by water. Each mass at Blackhall Rocks and elsewhere is generally surrounded by thin concentric layers of altered material, which must be broken away to reach the fossiliferous rock inside.

[1] R. Howse, 'Guide to the Collections of Local Fossils in the Hancock Museum,' 1889, p. 10, records a fragment of a coniferous plant from a laminated mass in concretionary rock near Westoe.

V. Nature of the Shell-Limestone and the Associated Strata.

One of the most conspicuous features of the Permian of Durham is the ridge or bank of more or less regular, dome-shaped masses of Shell-Limestone which lie in a belt from 2 to 4 miles wide in a north-westerly and south-easterly direction. Commencing with a fragment on Tynemouth Cliff, it occurs north of the Wear at Down Hill and Hylton Castle, passes by Claxheugh Rock and Pallion, Humbledon and Tunstall Hills, Ryhope, Dalton-le-Dale, Hawthorn, Beacon Hill, Easington Colliery, Horden, and Castle-Eden Dene, until it touches the coast at Blackhall Rocks; after this it reappears in Hesleden Dene, and thence presumably passes under Hartlepool.

The presence of these masses of Shell-Limestone and the condition of the beds upon their eastern flank have been the determining factor in the nature of the coast-section between Sunderland and Hartlepool.

The Shell-Limestones of the Middle Magnesian Limestone form an irregular chain of reef-knolls, lying in a band more or less parallel with the old Pennine shore-line. They are the chief repository of the fossils of the Magnesian Limestone, the classical localities being Humbledon and Tunstall Hills, both south of Sunderland.

The most probable view of the origin of these bryozoonal reefs would seem to be that they represent areas of comparatively sulphate-free deposition in the Permian sea, where the fauna, in consequence of greater purity of the water, would congregate and thrive. Assuming this, then, to be the true explanation, it will be seen that this rock, owing to its greater freedom from more soluble constituents, is to-day practically unaltered in volume; while the surrounding strata, more particularly the equivalents of the Shell-Limestone upon its eastern flank, have undergone structural collapse and degradation, leaving the Shell-Limestone as the elevated ridge or bank which forms so conspicuous a feature of the geology of the county.

This supposition, the plausibility of which can hardly be denied, in view of the already demonstrated replacement of Magnesian Limestone by sulphates in the Hartlepool area, certainly affords a ready explanation of many extremely puzzling features observable at various points on the coast-line where beds of Upper Limestone are brought down against, and frequently occur on a lower level than, the bank of Shell-Limestone.

The strata on the western and eastern sides of the ridge of Shell-Limestone in the southern area of the county, that is, on the side facing the Pennine shore-line and on the off-shore side of the Shell-Limestone reefs, are markedly different one from the other.

In the northern area of the county the western escarpment of the Shell-Limestone occurs directly upon the Lower Limestone, and generally only a short distance to the east of the great main Permian escarpment.

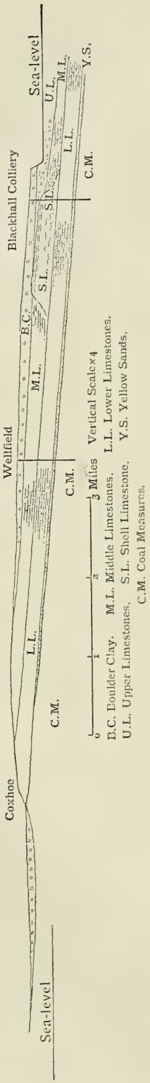


Fig. 3.—*Ideal section of the Permian, from the shore at Blackhall Colliery to the Escarpment near Coxhoe.*

In the southern area, roughly south of a line drawn from about Dalton-le-dale to Hetton, the Shell-Limestone rapidly passes westwards into a series of well-stratified beds, often profoundly altered, but not so completely collapsed and brecciated as are the equivalent beds on the eastern side. In the area under discussion the passage is well seen in Castle-Eden Dene, where at several points the beds are comparatively unaltered, and yield a scanty but characteristic fauna sufficient to fix their Middle Limestone horizon.[1] They cover a very considerable area of country in the southern half of the county. In the northern area both these beds and the uppermost Shell-Limestones are wanting, presumably through denudation. It will be seen then, that despite the greater poverty of exposures, the Permian succession is more complete in the southern than in the northern part of the county. (See fig. 3.)

The Upper Limestones have not hitherto been recognized upon the western side of the ridge; on the eastern side, however, matters are different. Here we find the various members of the Upper Limestones both overlying and flanking the side of the Shell-Limestone, which in elevated visible sections slopes very rapidly down to the sea-coast, corresponding to the original eastern side of the reef.

Whether or no the Upper Limestones were ever deposited west of the Shell-Limestone reef is still an open question. In Hesleden Dene and at Blackhall Colliery, for instance, and presumably at Hartlepool, they certainly overlie the Shell-Limestone; but a common position for them, especially evident in the shore-sections, is down upon the eastern side of the bank of Shell-Limestone.

The Upper Limestones may, of course, have been deposited in part upon the flanks of an elevated ridge or reef of Shell-Limestone, in which case one might reasonably expect to find derived fossils of the Shell-Limestone included in the Upper beds. No fossils have yet occurred to my knowledge in the highly-altered Middle Limestones on

[1] A list of the fossils found in these beds is tabulated in the last column on p. 215. The most interesting form is *Astarte vallisneriana* King, hitherto recorded only from the Lower Limestone at Whitby.

the eastern side; but the Concretionary Series and the overlying Hartlepool or Roker Beds are, of course, full in places of their scanty but characteristic fauna.

In my opinion [1] part of the Upper Limestones owe their present position on the side of, and at a much lower level, than the Shell-Limestone, to an irregular series of slip-faults caused by the degradation of the underlying, originally sulphate-bearing equivalents of the Middle Series.

As a general rule, therefore, in the southern part of the county, where the Shell-Limestone retreats from the shore-line or passes beneath the surface, the Upper Limestones are exposed in the shore-section. Where the Shell-Limestone approaches the shore or forms a high elevation immediately behind the coast, the shore-line and cliff-section are occupied by the highly-brecciated but well-bedded Middle Limestones occupying the lower flanks of the Shell-Limestone on its eastern side. These beds constitute large stretches of the cliff-section to the north of the area at present under discussion, and in general both these and the Upper Limestones dip rapidly away eastwards from the Shell-Limestone.

The extreme complexity of parts of the Durham coast-section will, therefore, be readily realized.

The typical Shell-Limestone is in general a hard, fine-grained magnesian rock, usually without very definite planes of bedding except in its upper parts, but is easily recognizable by its organic remains.

The accumulation of certain forms of marine life in the Shell-Limestone may have been induced by the action of currents in the Permian Sea, with consequent increase in the rapidity, and change in the character, of the sedimentation. Whatever may have been the inducing cause or causes, however, it is a true reef accumulation, the reef-builders in this case being predominantly bryozoa (taking the place of corals), brachiopods, lamellibranchs, gasteropods, ostracods, and, in the lower beds, crinoids.

[1] This is not mere conjecture. The faults which bring down the concretionary beds against the Shell-Limestone north and south of Blackhall Rocks are of this order.

At Beacon Hill, a knoll of Shell-Limestone facing the coast immediately south of Hawthorn Dene, the brecciated beds now lie in a sort of platform at the base of the hill, and form the whole of the cliff-section. A fissure in the breccia contains fallen masses of Upper fetid and fossiliferous Limestones of the concretionary series. The whole mass now occupies a lower level than the Shell-Limestone, with a fauna placing it about the middle of the Shell-Limestone and including *Productus horridus*. This rock is well exposed in a cutting for the new Coast Railway, which runs at the foot of the hill upon the platform of breccia. Part of the side of the Shell-Limestone reef has been stripped off in the railway-cutting, and slickensided surfaces are seen on the bank of Shell-Limestone passing vertically down the slope, indicating the downward movement of beds formerly adjacent to the now bared slope of Shell-Limestone. The Middle Breccias in the cliff are much segregated and unfossiliferous.

Beacon Hill, therefore, represents the original eastern slope of the ancient Permian reef, and is one of the best sections of Shell-Limestone at present exposed. A quarry at the top of the hill shows a bedded Upper Shell-Limestone with a typically impoverished fauna.

There appears to have been a comparatively rapid though tranquil accumulation of remains of these organisms. The delicate hollow spines of *Strophalosia* and *Productus* are preserved intact, and the valves of lamellibranchs throughout the Shell-Limestone are in most cases still articulated by the ligament, and separated merely to the extent naturally resulting from the decay of the animal.

The great accumulation of marine life indicated by the Shell-Limestone does not seem to have been adversely affected by the presence of magnesian salts. Every sample of the typical, unsegregated, often profusely fossiliferous rock, taken from all horizons, that I have analysed, shows a uniformly high percentage of magnesium carbonate, ranging generally from 40 to 45 per cent.

By whatever means the magnesia gained access to a rock such as the Shell-Limestone, or its equivalent beds on the eastern or western side, which, when unsegregated, show a similar composition, its presence is undoubtedly an original and contemporaneous feature of the formation.

The phases of the Upper Shell-Limestone exposed in the Hartlepool area may be tabulated as follows, in descending order, with their visible thickness in each section and the most obvious faunal features. The sequence must not be taken as a constant one, as the Upper Shell-Limestones probably thicken southwards:—

Shell-Limestones exposed in the Hartlepool Area.

	Thickness in feet.	*Faunal Features.*
Uppermost Bedded Shell-Limestones. (Upper end of Hesleden Dene.)	60	Brachiopod species, 2. *Strophalosia* very rare. Intense dwarfing of fauna. Gasteropoda, *Bakevellia antiqua*, and *Epithyris* very common but dwarfed and variable.
Shell-Limestones with interbedded Conglomerates. (Blackhall Rocks and lower end of Hesleden Dene.)	40	Brachiopod species, 3. *Strophalosia* rare. Typical middle forms very dwarfed. *Epithyris* common, but localized. *Bakevellia ceratophaga* very common.
Bryozoonal Shell-Limestones. (Castle-Eden Dene; Ivy-Rock section.)	80	Brachiopod species, 4. Dwarfing less apparent. *Strophalosia* very common. Bryozoa as reef-builders.
Bryozoonal Shell-Limestones. (Castle-Eden Dene; Deneholme section.)	20	Brachiopod species, 6. *Camarophoria schlotheimi* and *Trigonotreta multiplicata* appear.

In Blackhall-Colliery Sinking the full thickness of Shell-Limestone (about 335 feet) was encountered, and proved to exist beneath the surface in the district.

The upper part of the Shell-Limestone, which alone occurs in the outcrops in the area under consideration, with its impoverished and dwarfed fauna, was clearly indicated as overlying the typical highly-fossiliferous rock, with profusion of brachiopods and other

forms, which is so characteristic of the northern area of the county. This upper or *Productus*-free phase, so far as I could ascertain, had a thickness of about 150 feet in Blackhall Sinking.

The fauna of the uppermost Shell-Limestones approaches in character that of the brachiopod-free Upper Limestones. It is characterized by (*a*) the comparative absence of brachiopoda, (*b*) the abnormal dwarfing of many typical Shell-Limestone forms, (*c*) the numerical profusion of certain genera which are characteristic of the Upper Limestones (*Turbo* and other small gasteropoda, *Myalina*, *Schizodus*, etc.).

The increasingly unfavourable conditions that prevailed towards the top of the Shell-Limestone bring about the gradual extinction of all the typical brachiopod genera, except *Epithyris* and *Strophalosia* (many of the largest and most conspicuous forms, such as *Spirifer alatus* and *Athyris pectinifera*, being the first to disappear, followed shortly by *Productus* and the large *Camarophoriæ*). The more adaptable lamellibranchs persist, though many in a dwarfed condition. *Pleurophorus* survives the ordeal, although dwarfed to about a third of its normal size, and persists throughout the Upper Limestones. The gasteropod genus *Turbo* is comparatively unaffected, as its great numerical abundance in some beds in Hesleden Dene and at Blackhall Rocks testifies.

The profusion of small littorinoid gasteropods and mytiloid lamellibranchs might be considered as evidence of influence of littoral conditions in the upper beds of the Shell-Limestone. The beds of small gasteropoda may be taken as evidence of shallowing water over the reef,[1] but neither the composition of the rock which maintains its uniform highly magnesian character, nor any increase in the insoluble residue, indicate any change from the conditions prevailing in the typical lower beds of the Shell-Limestone.

The reason for the decadence of the fauna is more probably to be sought in the increasing amount of sulphates in the sedimentation, following upon the gradual failure of the conditions which gave rise to the formation of the Shell-Limestone. This view seems to be further favoured by the great amount of bedding (regular and irregular) and internal deformation, at present observable in all sections in the Upper Shell-Limestones in the district, as also the association with them of unfossiliferous beds containing the cavities, presumably left by sulphates, already described.

VI. Typical Sections and Exposures in the Hartlepool Area.

(1) Hartlepool Foreshore.

The cliff-section is now greatly obscured by the sea-walls, but the main succession may be studied and Upper-Limestone fossils collected at various points at low tide.

[1] J. W. Kirkby, Q. J. G. S. vol. xiii (1857) p. 218.

		Thickness in feet.	Fauna.
Highest Limestones. Hartlepool Series.	Soft, white, porous, friable, well-bedded limestones, showing dendritic specks on fractured surfaces. Calcite-lined geodes and small brown fluorites occur	30	*Schizodus schlotheimi* Gein. *Mytilus septifer* King.
	Massive bedded 'roestone' in part of section, enclosing large flattened lenticles of powdery material	20	No fossils.
	Variablê, hard and soft, white and yellow limestones. Fossils generally obliterated, but some occur in the harder parts of the rock west of the new breakwater	35	*Schizodus schlotheimi* Gein. *Pleurophorus costatus* Brown. *Mytilus septifer* King. *Turbo helicinus* Schl. *Natica* cf. *leibnitziana* King. Small indeterminate gasteropoda.

At Brunswick Brewery, Hartlepool, a boring was sunk to 100 feet in the limestone; but no trace of anhydrite or gypsum was met with.

In Victoria Dock the limestone was struck on the east side of the dock, at a depth varying between 14 and 23 feet beneath Boulder Clay; but on the west side, 350 to 400 feet westwards, the depth had increased to 36 and 50 feet. This is apparently not the dip of the beds, but represents the westward slope of the old pre-Glacial 'slack' or valley of which the anhydrite-mass forms the floor.

(2) West Hartlepool.

Limestone of this outcrop is well exposed in a quarry near the waterworks, and in the railway-cutting on the east.

The following section may be seen in the quarry:—

		Thickness in feet.	Fauna.
Highest Limestones.	Thin, well-bedded layers of soft, yellow, decayed, extremely porous limestones, interbedded with hard bands a few inches thick. Associated with these are several beds, 1 to 2 feet thick, of a soft yellow rock showing a granular oolitic structure. Traces of fossils are abundant in some bands, but are nearly obliterated	30	*Schizodus schlotheimi* Gein. *Mytilus septifer* King. *Pleurophorus costatus* Brown.

A boring at the waterworks shows that these beds continue to a depth of 39 feet from the bottom of the quarry, when an extremely hard limestone is met with, having a thickness of 9 feet. Beneath this the details of the boring are unreliable, but it was carried to 69 feet without encountering any trace of anhydrite or gypsum. Samples of the above-mentioned limestone were found

lying round the wells, but no fossils could be detected in them. The limestone is similar in appearance to the flaggy beds which underlie the Uppermost Limestones in the Hesleden-Dene section. It is a well-bedded brown and grey fissile rock of extreme hardness, containing nearly 43 per cent. of a fine siliceous residue.

(3 *a*) Blackhall Rocks.

This is the only spot on the Durham coast where the true Shell-Limestone is exposed in the shore-section. The Shell-Limestone reef occurs only a short distance inland all the way down the coast from Sunderland to Hesleden Dene; but the actual exposures of rock on the shore are either the Upper Limestones or the unfossiliferous breccias which occupy the eastern flank of the Shell-Limestone. The section is as follows:—

		Thickness in feet.	*Fauna.*
Upper Shell-Limestones.	Dusty, porous, decayed limestones. Generally well-bedded and occasionally massive. Much collapsed. Hollow pseudomorphic aggregates after sulphates plentiful in places ...	60	No fossils.
	Peastone in part of the section ...	2	No fossils.
	Upper Shell-Limestone with interstratified conglomerates. Large and small irregular rounded masses of variable hardness. In parts apparently piled together indiscriminately, in other parts in distinctly stratified order. Several bands of bedded limestone appear between the layers of rounded fragments. Hard limestone showing much internal deformation...............	40	Dwarfed and impoverished Shell-Limestone fauna.[1] A band of small gasteropoda and other forms occurs locally about the middle of the conglomerate.

Base not seen.

[1] Lists of these fossils are given in tabular form in § VII, p. 215.

The Middle Limestones are here exposed over a length of slightly under a mile of coast-line. Both north and south of this section the Upper Limestones are faulted down against the Middle Limestones, the incoming beds being in each case the Concretionary Series.

The well-known caves at this place are due to the rounded masses of Shell-Limestone Conglomerate becoming detached by the action of the sea, and leaving the overlying bedded limestones as a roof to the caves.

Southwards, the overlying beds occupy the cliff-section until the fault at Cross Gill is reached; but they change considerably

in character. Slightly north of the fault the following section occurs :—

		Thickness in feet.	
UPPER MIDDLE LIMESTONES.	Massive white limestone, assuming a 'roestone' structure and developing hard calcareous spongy breccias for some distance north of the fault. Layer of small yellow brecciated fragments, thinning out before the fault is reached. Thinly stratified limestone, very loosely compacted, showing traces of large lenticular inclusions now removed	60	No fossils.

Between the fault and the incoming Concretionary Series a well-defined space intervenes, filled with a soft collapsed mass of comminuted white-and-yellow fragments of a fetid limestone. The bedding is visible in part, and a band of limestone at the base dips rapidly southwards; this seemingly indicates that the beds next encountered have been carried downwards.

(3 *b*) Coast-Section south of Blackhall Rocks.

The coast-line between Cross Gill and the Targets at Hart is occupied by the lower series of the Upper Limestones, here forming two divisions, of which only the lower shows any concretionary structure. In no case is that structure developed to the extent observed in the Sunderland area. The section is as follows :—

		Thickness in feet.	Fauna.
CONCRETIONARY LIMESTONE.	Thinly-bedded, well-stratified yellow limestones, frequently brecciated and collapsed. Fossils occur lying on a matted ground of rods of *Filograna*. Sections of this fossil are visible in the face of the cliff as small circular punctures	35	*Filograna (?) permiana*[2] King. *Schizodus schlotheimi* Gein. *Mytilus septifer* King. *Natica* sp.
	Hard, fissile, fetid, flaggy limestones with interstratified beds developing concretionary, botryoidal, and cannon-ball structures. Associated with these (as matrix of the concretions) are soft, fetid, grey or brown marly-looking[1] limestones, occasionally massive, generally much brecciated and collapsed. .	50	*Schizodus schlotheimi* Gein. *Mytilus septifer* King. Slabs of concretionary limestone, with crowded masses of testiferous specimens occur.
	Base not seen.		

[1] Incorrectly described by early writers as 'marl' or 'marly limestone.' It yields practically no clayey residue on solution, but much oily organic matter.

[2] W. King, 'Monogr. Perm. Foss. Engl.' (Pal. Soc.) 1850, p. 56.

(3 *c*) Coast-Section from Blackhall Rocks to Castle-Eden Dene.

This section measures slightly over a mile. The southern part embodies a section of the Concretionary Series similar to that already described. The fault that brings down the concretionary beds occurs a short distance north of Blackhall Rocks. It is apparently of slightly greater throw than the corresponding fault on the south.

The northern part of the section, across and beyond the mouth of Castle-Eden Dene, exposes the following beds:—

		Thickness in feet.	*Fauna.*
UPPERMOST LIMESTONES.	Very soft, white and yellow, powdery limestones, associated with a 'roestone' well seen on the shore. Both are pierced and interbanded with irregular masses of yellow, crystalline, calcareous material which retains in part the 'roestone' structure. The oolitic grains are filled with aggregates of brown fluorite-crystals	25 (?)	*Schizodus* sp.

Owing to the complication of the cliff-section by glacial action and fallen sand and clay, it is impossible to ascertain the thickness of either these or the concretionary beds.

(4) Hesleden Dene.

A post-Glacial ravine extending in a more or less east-and-west direction for a distance of about 4 miles. The stream has cut a gorge in the limestone, laying bare a good and continuous section of the Middle and Upper Magnesian Limestones for about 3 miles. The limestone is first met with about half a mile from the dene mouth. Between the two railway-viaducts which cross the dene, the stream passes through a gorge where the following section of Upper Shell-Limestone is exposed, and can be studied both in the gorge and in an old quarry in the dene close by:—

		Thickness in feet.	*Fauna.*
UPPER SHELL-LIMESTONES.	Hard, bedded, Shell-Limestones. Thinly-bedded limestone in part of the section. Interbedded conglomerates rounded, or angular and much broken up. The masses consist of typical, fine-grained, compact Shell-Limestone. Hard limestones, more or less bedded, showing locally much internal deformation	35	Dwarfed and impoverished Shell - Limestone fauna similar to, but scantier than, that of Blackhall Rocks.

Prevailing dip of the beds = about 5° east-south-eastwards.

These beds very closely resemble the Shell-Limestone Conglomerate of Blackhall Rocks and are probably equivalent thereto. They very likely owe their existence here to a fault west of the gorge which cannot now be traced, but may lie beneath the railway-embankment.

On crossing the railway one meets with the Uppermost Limestones (Hartlepool or Roker Series). The beds now dip more or less regularly eastwards and south-eastwards at a small but variable angle, so that older beds are encountered as one ascends the stream until finally the highest Shell-Limestones are met with at the upper end of the dene.

Owing to the rapid lateral alteration of some of the beds, the sequence must not be regarded as a constant vertical section. The succession is as follows :—

		Thickness in feet.	*Fauna.*
HIGHEST LIMESTONES. HARTLEPOOL OR ROKER SERIES.	White limestones, well-bedded, massive in part. Thinly bedded in the upper and lower parts. A massive bed, with much cross-jointing, is quarried as a building-stone	30	*Schizodus schlotheimi* Gein. *Mytilus septifer* King. *Pleurophorus costatus* Brown. *Natica (?)* sp.
	Thin bed of 'roestone,' comprising large and small irregular lenticles. Very highly fossiliferous	4	Same as above.
	Indurated and partly-segregated white limestones, developing a porous and irregular breccia in parts. Occasionally much cross-jointed. The 'roestone' structure is maintained, despite induration	25	Same as above.
(?) EQUIVALENTS OF THE CONCRETIONARY SERIES.	Well-bedded, thin, hard limestones, white and yellow, and slightly fetid. Soft at the top, where they are much broken up and cross-jointed. The lower part consists of a fine-grained grey and yellow limestone with cavities, as a rule very thinly bedded. (Well seen near Temps Hole.)	20	No fossils.
	Honeycomb breccia with powdery material	10	
	Well-bedded, yellow, comminuted breccia	2	No fossils.
	Spongy breccia, much broken up	10	
	Very regularly bedded, yellow limestones, consisting of coarse-grained, soft, yellow beds, occasionally much broken up and jointed, intercalated with bands of thin, hard, yellow, fissile limestone. Massive in part, with a hard honeycomb breccia at the base	25	No fossils.
UPPERMOST SHELL-LIMESTONES.	Well-bedded, porous, partly massive limestones	6	*Bakevellia ceratophaga* and small gasteropoda.
	Variable, hard and soft, more or less bedded limestones showing intense internal deformation, with pockets of powdery material enclosing portions of hard, granular, porous, comparatively unaltered rock in stratified masses. Massive honeycomb breccias developed locally	50	Very dwarfed and scanty Shell-Limestone fauna. Many fossils, especially in the lower part, where bands full of *Epithyris* and small gasteropoda occur.
	Base not seen.		

There is apparently in Hesleden Dene a perfectly conformable passage, down from the Uppermost White Limestones to the Upper Shell-Limestone, without any trace of development of concretionary structure. Neither the typical fossils nor any trace of *Filograna* occur in the presumed equivalents of the Concretionary Series. The same applies to the Hardwick-Dene section.

The Shell-Limestones are exposed for a distance of over a mile, coming in at Jackdaw Rock, at which point the overlying yellow fissile limestones dip sharply south-westwards at an angle of about 15°, and ending with the disappearance of the rock beneath Boulder Clay at the top of the dene.

Overlying and partly replacing the Shell-Limestones is a series of soft, white, bedded limestones, very porous and friable, but occasionally massive, with dusty cavities arranged along the planes of bedding. They are often full of hollow cavities, presumably pseudomorphic after sulphates. These beds are excessively tumbled and collapsed in part, with development of calcareous ribs and irregular segregated breccias.

From the nature of the fauna as well as from their position, the beds at the upper end of Hesleden Dene are regarded as the highest Shell-Limestone that occurs in the county of Durham.

(5) Castle-Eden Dene.

This is a ravine extending in a north-easterly and south-westerly direction for a distance of nearly 5 miles. The valley is of pre-Glacial origin, and upon the Boulder Clay that fills the pre-Glacial wash-out the present stream has been superimposed. The stream apparently coincides with the line of the pre-Glacial wash-out in only the last part of its course, and empties itself into the sea near the northern boundary of the original valley, which has a width of about a third of a mile.

The result is that the stream has in places cut a very deep gorge into the rock, exposing a fine and nearly continuous section in the Middle Magnesian Limestones for a distance of over 3 miles.

The strata in the shore-section at the mouth of the dene, as already described, belong to the Uppermost Limestones, and are here probably faulted down against the bank of Shell-Limestone.

The following section of Shell-Limestone is exposed near the entrance of the dene, between Deneholme and the railway-viaduct, in the bed and on the southern bank of the stream:—

		Thickness in feet.	*Fauna.*
UPPER SHELL-LIMESTONE.	Grey and yellow, crystalline, fine-grained limestones of variable hardness, passing locally into breccias of varying degree of fineness, in which irregular pockets and masses of powdery material occur. Fossils in all stages of preservation, from perfect preservation to complete obliteration	20	A highly bryozoonal limestone, with plentiful ostracods. Rock largely made up of comminuted fragments of various organisms.

The Shell-Limestone is again finely exposed between the Garden-of-Eden Bridge and White Rock.

At Craggy Bank a good exposure of very fossiliferous rock occurs on the south side of the stream, some distance up the bank. It is here broken up into large and small irregular angular fragments, which however are in undisturbed position.

At Ivy Rock the following fine section is laid bare in an overhanging cliff about 80 feet high, where the position of the abovementioned angular breccia can be seen about the middle of the exposure :—

		Thickness in feet.	*Fauna.*
UPPER SHELL-LIMESTONES.	Hard, massive, variable, indurated beds, much broken up. Fossiliferous in places	30	*Nautilus* at the base.
	Highly-fossiliferous angular breccia	15	Highly bryozoonal limestone.
	This passes gradually but rapidly down into a soft powdery mass, much cross-jointed, enclosing bands of harder material, in which the fossils are still recognizable in the layers directly underlying the breccia	35	
	Thin, stratified, soft, uncollapsed bed of porous limestone in the stream	2	Casts of *Bakevellia antiqua* and small gasteropods.

The prevailing dip of the Shell-Limestones, about 5° to 10° eastwards, brings up the underlying soft powdery beds, until at White Rock they occupy the whole of the cliff on each side of the stream, giving a very conspicuous section as follows :—

		Thickness in feet.	*Fauna.*
SHELL-LIMESTONE MERGING INTO THE STRATIFIED WESTERN EQUIVALENT.	Yellow and white powdery friable limestone. Lines of stratification distinctly indicated by bands of harder and less altered, but still very porous, limestone. Section practically homogeneous throughout	80	All traces of fossils apparently obliterated.

Passing downwards and westwards the beds become less altered, the white powdery rock merging gradually into a well-bedded fine-grained limestone. The intermediate phase is well seen in the cliff above the stream opposite Seven Chambers, where the powdery material, accompanied by some calcareous segregation, becomes subordinate to bands of unaltered rock containing fossils.

Between this place and Gunner's Pool many fine sections of comparatively unaltered bedded limestones are exposed, representing the equivalents of the Shell-Limestone on the western side of the reef.

At Devil's Bridge the following section is laid bare :—

		Thickness in feet.	*Fauna.*
MIDDLE BEDDED LIMESTONES.	Well stratified, fine-grained, thinly bedded, hard, and slightly-fetid limestones. Generally almost unaltered, though brecciation and segregation are present to a small extent. Strata often very much fractured at right angles to the planes of bedding. Flattened hollow spaces (left by sulphates?) present in some of the less altered portions	60	Vermes, lamellibranchs, and ostracoda. Bryozoa and brachiopods entirely absent.

At Gunner's Pool and Bruce's Ladder the above-described beds have undergone much alteration, and calcareous segregated bands are seen intercalated with yellow powdery material. The latter is very apparent at the top of the section, but lower down has been largely removed. The calcareous bands here coalesce, forming a typical honeycomb breccia merging downwards into a hard unyielding thick bed of limestone which offers an obstacle to the stream. The whole mass is pierced with vertical fissures in various directions, through one of which the water finds its way. The fine wall of rock at the base of which the stream emerges is the face of another fissure, and affords a good section of these much altered rocks. The whole gorge is one of great natural beauty, and in parts is thickly hung with ferns. Fossils are entirely obliterated.

Beyond this section, towards the upper end of the dene, the beds are less altered. Near an old quarry the following section is exposed in the side of the stream:—

		Thickness in feet.	*Fauna.*
MIDDLE BEDDED LIMESTONES.	Well-bedded, thin, yellow limestones. Very highly fractured at right angles to the bedding. Collapsed in part, with powdery material	6	*Astarte vallisneriana* King. *Schizodus* sp.

(6) Hardwick Dene.

This is a small, post-Glacial ravine passing in a north-and-south direction for slightly under a mile, and joining Castle-Eden Dene about half a mile from the sea. The stream has in places cut into the rock to a depth of 40 feet, exposing a good section of the Upper Limestones. The ravine rises rapidly, and the dip of the strata is very variable, but higher beds are encountered as one ascends the stream:—

		Thickness in feet.	*Fauna.*
UPPERMOST LIMESTONES. HARTLEPOOL OR ROKER SERIES.	Soft, yellow, well-bedded, rotten limestones, which enclose large, rounded, hard masses containing a few fossils	30	*Schizodus schlotheimi* Gein. *Mytilus septifer* King. Small gasteropoda.
	Small-grained 'roestone,' partly indurated		No fossils.
	Soft yellow limestone, more or less collapsed and brecciated, especially in the lower part	20	*Schizodus* and *Mytilus* abundant in a less altered band.
	Hard honeycomb breccia. 'Roestone,' very porous in the lower beds. Large and small, flattened, irregular, lenticular bodies very apparent	50	No fossils.
(?) EQUIVALENTS OF THE CONCRETIONARY SERIES.	Thinly-bedded, fissile, well stratified, white and yellow limestones of marly appearance, much brecciated and powdery in places. These beds become extremely white, porous and friable in part with dusty cavities	30	No fossils.
(?) SHELL-LIMESTONE.	Hard, angular, limestone-breccia, the masses embedded in yellow powdery material	20(?)	No fossils seen.

(7) Hart Quarries.

Nearly 2 miles to the west of the waterworks at West Hartlepool, the land rises rather rapidly to the 200-foot contour-line which corresponds with an outcrop of limestone. It probably owes its presence here to a fault which cannot, however, be definitely located.

The limestone is well exposed in three quarries on the west side of the road from Hart to West Hartlepool, in a quarry at Hart Windmill, and in a large quarry near Naiseberry, south-west of High Throston, about a mile from the Ward-Jackson Park at West Hartlepool.

As the last-named section is the most typical, and the only one where any traces of fossils seem to have been preserved, it is here described :—

		Thickness in feet.	*Fauna.*
(?) HIGHEST LIMESTONES.	Very hard, dense, brown and ashen grey, segregated limestones. Irregularly bedded, but stratification very apparent, brecciated in places. Powdery constituent entirely removed.	25	Fossils obliterated.
	'Roestone' in part of section.	6	No fossils.
	Extremely soft and friable, well-bedded yellow limestones, showing 'roestone' structure in places.	6	*Schizodus* sp. *Mytilus* sp.

Fossils found in these beds were in the last stages of obliteration. The genera are recognizable, but specific determination is hardly possible. They would seem to justify the reference of the beds in all these quarries to the Uppermost Limestones, here protected from denudation by the overlying mass of segregated calcareous material.

Similarly altered beds occupy a very considerable area of country on the west. The surface-contour of these beds is extremely variable, determined no doubt by the different hardness of the calcareous and magnesian portions of the rock.

Such rocks are exposed in quarries at Wellfield, Wingate, Trimdon, Haswell, etc., where in most cases they can be shown on palæontological evidence to represent the western equivalent of the Shell-Limestones.

A somewhat similar limestone is exposed in a quarry at Whelly Hill, near the intersection of the Durham, Hartlepool, and Stockton roads. It lies very slightly above the 400-foot contour :—

		Thickness in feet.	*Fauna.*
(?) MIDDLE LIMESTONE.	Collapsed, recemented calcareous fragments forming a rather massive bed....................	4	
	Very thinly-bedded limestones, white and yellow, showing great internal bending; towards the base the rock becomes spongy and associated with powdery material. Hollow spaces left by sulphates are very numerous, causing the collapse and brecciation of the overlying part	30	No fossils.

(8) Blackhall-Colliery Sinking (1909–13).

This sinking has been of great help in elucidating the structure of the district, and shows that the normal Permian succession exists beneath the Upper and the Upper Middle beds exposed at the surface.

It is situated almost midway between the typical exposures of Upper Shell-Limestone of Blackhall Rocks and Castle-Eden Dene, and is probably the only sinking that pierces the whole thickness of the Shell-Limestone, though it is situated not on the centre, but near the eastern slope of the reef.

Two shafts were sunk, the northern and the southern shaft, 165 feet apart. A drift to carry off the water was sunk between these and the sea, 210 feet east of the shafts, to a depth of 246 feet.

The following section is drawn up, both from data which I obtained myself, and from examination of rock-samples taken from authenticated levels, in the possession of the Horden Collieries Company, Ltd. It represents the section in the southern shaft. The thicknesses given for the Upper Limestones are not absolutely certain. The total thickness of the Permian strata is 688 feet, and the depth of the base of the sand-bed from the surface is 756 feet.

		Thickness in feet.	*Fauna.*
	Boulder Clay	68	
Highest Limestone	Broken limestone, similar to a bed exposed in the railway-cutting near by. It has a roe-stone in part	19	No fossils seen.
Concretionary Limestones.	Limestones with well-developed concretionary structure	(?) 63	No fossils seen.
Upper Shell-Limestone.	Shell-Limestones of variable character	155	Highly fossiliferous, but with a restricted fauna.
Main Shell-Limestone.	Typical Shell-Limestones	180	Profusely fossiliferous. Fully developed fauna. Masses of bryozoa at several levels.
Lower Limestones.	Yellow, bedded, friable limestones. Brown friable limestone. White friable nodular limestone. Hard brown and white bedded limestones. Very hard, brown, banded limestones, with carbonaceous partings	240	Fragments of bryozoa and drifted plant-remains. No fossils seen.
Marl-Slate.	Compact dark-grey and black shales	5	*Palæoniscus, Platysomus, Pygopterus*, etc. with coprolitic matter. Also *(?) Posidonomya.*
Yellow Sands.	Sand-bed, very compact in parts, resembling a dark-grey sandstone-conglomerate. Enclosing pyrite in cracks and veins	26	No fossils seen.

I am told that when the stratified beds at the top of the Lower Limestones were encountered beneath the Shell-Limestone, the dip was found to be due south, at an angle of 16°; and that, in consequence, these beds occurred 50 feet lower in the southern than in the northern shaft. However, when the Marl Slate was reached in the former shaft, the dip was a very slight one to the south-east, whence we may infer that the disturbance of the upper part of the Lower Limestone was a local phenomenon.

In the drift, 210 feet east of the shafts, beneath the Boulder Clay, an incoherent, soft, yellow limestone of marly appearance, showing no stratification, was encountered, and pierced to a depth of 246 feet. It exhibits a distinct 'roestone' structure in samples which I obtained. The best explanation that I can offer of this sudden change is that here we are off the reef of Shell-Limestone, and that this substance is part of the collapsed Upper Limestones occupying the eastern slope of the reef.

VII. Notes on the Palæontology of the Hartlepool Area.

The changed conditions represented by the Middle Limestones in the Durham area, while introducing at least thirty new species, gave the Lower Limestone fauna, so to speak, a new lease of life under the protection of the Shell-Limestone bryozoonal reefs. There is evidence to show that this sudden influx was never repeated, but that the fauna was caught and trapped in a sea isolated from the oceans. Its adverse fortunes and gradual decadence and extinction, following on the slow failure of the conditions which inaugurated it, can be studied as we ascend in the Shell-Limestones.

Obviously, then, new species are hardly to be expected in the Upper Shell-Limestones, more especially as the material for the classical monographs was chiefly obtained from the highly fossiliferous localities of the main Shell-Limestone then open in the Sunderland area. Nevertheless, many of the typical forms described by King and others undergo considerable change as we ascend in the formation.

Owing to the continued absence of a revision of the Anglo-German Permian fauna in the light of recently investigated marine Permian faunas, the lists of fossils are somewhat unsatisfactory.

To avoid any confusion, I have based my identifications for all forms, except the brachiopoda, on King's Permian Monograph (1850). For the brachiopoda I have made use of Davidson's 'Monograph of British Permian Brachiopoda' (1857–62).

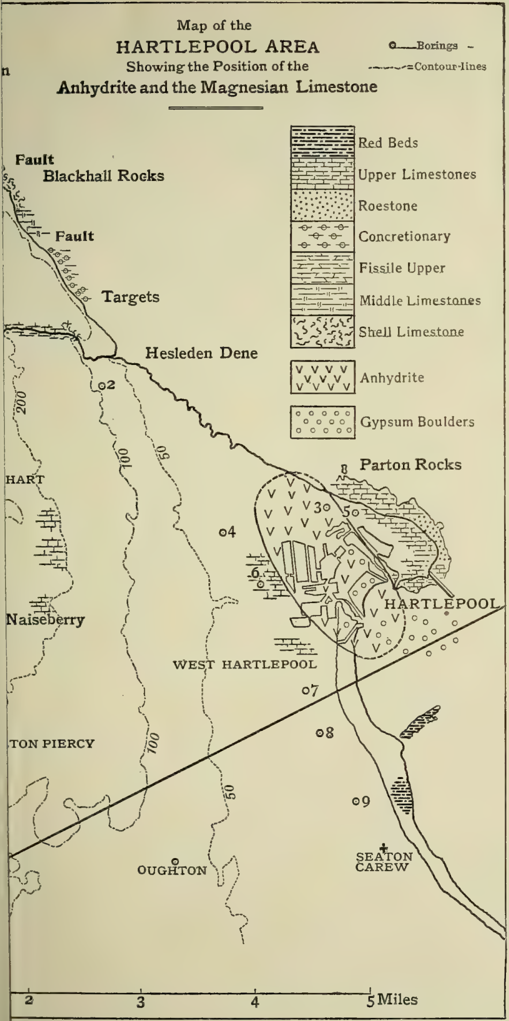
Fossils of the Middle Magnesian Limestones in the Hartlepool Area, showing the Gradual Extinction of the Fauna of the Shell-Limestone.

[The last column includes the fossils of the bedded western equivalents of the Shell-Limestone in Castle-Eden Dene. r=rare; c=common; v.c.=very common.]

Names of Species.	Lower Shell-Limestone.	Bryozoonal Shell-Limestones of Castle-Eden Dene.		Shell-Limestone Conglomerates.		Highest Shell-Limestones.	Bedded Middle Limestones.
	Blackhall Sinking: lower 150 feet.	Deneholme.	Ivy Rock.	Blackhall Rocks.	Hesleden Dene.	Upper end of Hesleden Dene.	Upper part of Castle-Eden Dene.
Vermes.							
Spirorbis permianus King	...	...	...	...	...	...	*
Serpula (?) pusilla Gein.	*	...	...	...	...	...	*
Vermilia obscura King	...	...	...	*	...	...	*
Anthozoa.							
Petraia profunda Germar	*	...	...	...	...	...	...
Bryozoa.							
Calamopora macrothii Gein.	*	...	*	r	...	...	...
Stenopora columnaris Schl.	*	...	...	...	...	...	...
Fenestella retiformis Schl.	*	*	*	r	...	...	...
Synocladia virgulacea Phill.	*	...	*	...	...	...	...
Phyllopora ehrenbergi Gein.	*	...	...	...	...	...	...
Thamniscus dubius Schl.	*	...	*	r	...	...	...
Acanthocladia anceps Schl.	*	*	*	...	...	?	...
Echinodermata.							
Cyathocrinus ramosus Schl.	*	...	...	...	...	...	...
Archæocidaris verneuiliana King	v.r.	v.r.	v.r.	...	...	...	...
Brachiopoda.							
Discina speluncaria Schl.	r	...	...	...	...	...	...
Productus horridus Sow.	*	...	...	...	...	...	...
Productus umbonillatus King	*	...	...	...	...	...	...
Strophalosia lamellosa Gein.	*	*	*	...	...	...	...
Strophalosia goldfussi Münst.	*	*	v.c.	r	...	v.r.	...
Streptorhynchus pelargonatus Schl.	*	...	...	...	...	...	...
Camarophoria schlotheimi v. Buch	*	r	...	...	...	...	
Camarophoria globulina Phill.	*	...	...	...	...	...	...
Camarophoria multiplicata King.	*	...	...	...	...	...	...
Trigonotreta alata Schl. and variants	*	...	...	...	...	...	...
Trigonotreta cristata Schl.	*	*	r	v.r.	...	...	...
Trigonotreta multiplicata Sow.	*	r	...	...	...	...	...
Cleiothyris pectinifera Sow.	*	...	...	...	...	...	...
Martinia clannyana King	*	...	...	...	...	...	...
Epithyris elongata Schl.	*	...	...	...	...	...	...
Epithyris sufflata Schl.	*	*	*	v.c.	v.c.	v.c.	...

FOSSILS OF THE MIDDLE MAGNESIAN LIMESTONES IN THE HARTLEPOOL AREA (*continued*).

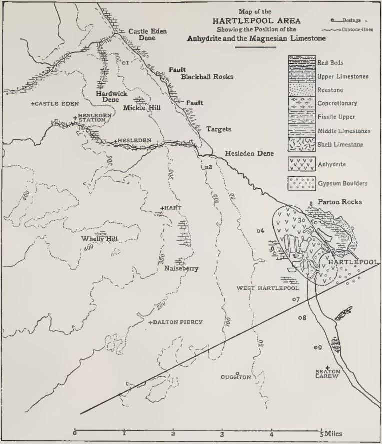
NAMES OF SPECIES.	Lower Shell-Limestone.	Bryozoonal Shell-Limestones of Castle-Eden Dene.		Shell-Limestone Conglomerates.		Highest Shell-Limestones.	Bedded Middle Limestones.
	Blackhall Sinking: lower 150 feet.	Deneholme.	Ivy Rock.	Blackhall Rocks.	Hesleden Dene.	Upper end of Hesleden Dene.	Upper part of Castle-Eden Dene.
Lamellibranchiata.							
Pecten pusillus Schl.	*	...	...	...	...	...	...
Lima permiana King	*	*	*	v.r.	...	...	...
Monotis speluncaria Schl.	*	c	c	c	...	...	...
Mytilus (Liebea) squamosus Sow.	*	...	...	c	c	...	...
Edmondia murchisoniana King	*	...	...	...	...	...	...
Bakevellia ceratophaga Schl.	*	*	*	c	c	r	c
Bakevellia antiqua Münst.	*	...	*	r	*	v.c.	*
Byssoarca striata Schl.	*	*	*	r	...	...	...
Byssoarca cf. *kingiana* de Vern.	...	...	*	...	...	...	...
Cardiomorpha modioliformis King	*	*	...	c	...	...	...
Pleurophorus costatus Brown	*	*	*	*	...	*	*
Schizodus truncatus King	*	*	...	*	...	*	*
Astarte vallisneriana King	...	...	...	...	...	...	*
Astarte cf. *tunstallensis* King	...	...	...	...	...	...	?
Allorisma elegans King	*	...	...	...	...	...	...
Gasteropoda.							
Chiton cf. *loftusianus* King	*	...	*	...	...	...	...
Turbo helicinus Schl.	*	*	*	v.c.	*	c	...
Turbo thomsonianus King	...	...	...	*	...	*	...
Turbo taylorianus King	*	...	...	*	...	*	...
Loxonema sp.	*	*	*	*	...	...	...
Macrocheilus sp.	...	...	...	...	...	*	...
Euomphalus permianus King	*	...	*	...	...	...	...
Natica leibnitziana King	*	*	*	...	*	*	...
Natica cf. *minima* Brown	...	...	*	...	...	?	...
Pleurotomaria antrina Schl.	*	...	*	v.r.	...	v.c.	...
Pleurotomaria tunstallensis King	?	*	*	...	*	v.c.	...
Pleurotomaria nodulosa King	*	...	...	...	...	...	...
Pleurotomaria linkiana King	*	...	...	...	...	...	...
Minute indeterminate gasteropoda	...	...	...	...	...	*	r
Cephalopoda.							
Nautilus freieslebeni Gein.	...	...	*	v.c.	*	...	...
Nautilus bowerbankianus King	*	...	...	*	...	...	...
Crustacea.							
Ostracoda	*	*	*	*	*	*	*



ist of Borings.

ck. | 7. Pulp-Works.
vick Brewery. | 8. Cement-Works, West Hartlepool.
works, West Hartlepool. | 9. Seaton Carew.

nhydrite mass. Victoria Dock lies to the east of this, and off the vards across the map from Hartlepool indicates a hidden fault-line.]



List of Borings.

1. Blackhall Colliery.
2. Hart.
3. Warren Cement-Works, Hartlepool.
4. Howbeck.
5. Brunswick Brewery.
6. Waterworks, West Hartlepool.
7. Pulp-Works.
8. Cement-Works, West Hartlepool.
9. Seaton Carew.

[The oval space shows the probable outline of the anhydrite mass. Victoria Dock lies to the east of this, and off the anhydrite. The thick black line running south-westwards across the map from Hartlepool indicates a hidden fault-line.]

VIII. Summary of Conclusions.

(1) The Magnesian Limestone, in the district here described, in its original condition of deposition contained very large quantities of calcium sulphate, as shown by several borings entering or piercing the Magnesian Limestone where it underlies the Red Beds or other protective covering.

(2) This calcium sulphate has been completely removed by the action of percolating waters, wherever the Magnesian Limestone has been divested of its protective covering of comparatively impervious Permian and Triassic red marls and the associated beds.

(3) A mass of anhydrite, apparently by reason of its exceptionally large size, has escaped complete removal; and, because its denudation and erosion were more rapid than was the case with the surrounding Magnesian Limestone, it has given rise to the 'slack' or valley which now accommodates the harbours of Hartlepool and West Hartlepool.

(4) This mass of anhydrite overlies a gypsiferous (protected) Magnesian Limestone containing fossils of the Middle Division (Shell-Limestone), and so must represent the time-equivalent of apparently part of the Middle, and of a great part of the Upper Limestones.

(5) Evidence goes to show that the sulphates in the Magnesian Limestone were originally deposited as anhydrite, and that this anhydrite was converted into gypsum before removal. The bands of limestone which are interbedded with anhydrite towards the base of the anhydrite-mass represent Magnesian Limestone in its original condition. The gypsiferous limestones which occur beneath the anhydrite-mass at Hartlepool or other areas represent an intermediate stage between the unaltered rock and the completely gypsum-free limestones at the surface.

(6) The removal of soluble sulphates from the formation has brought about a degradation and settling-down, with a consequent decrease in volume of the Magnesian Limestone, resulting in

(*a*) A mechanical collapse of parts of the strata with consequent brecciation; and (*b*) an intense porosity in those beds where the sulphates impregnated, or existed in close association with, the carbonates.

(7) The porous condition in which parts of the formation are left after removal of the sulphates lays it more open to processes of segregation and differentiation of the two carbonates, with production of hard calcareous breccias associated with powdery material rich in magnesium carbonate, which are an obvious feature of the formation in its present condition. The subsequent removal by water (by solution or by mechanical means) of the powdery material brings about the dedolomitization of parts of the formation on a more or less extensive scale.

(8) Analysis of obviously less-altered portions of the formation goes to show that the Middle and Upper Magnesian Limestones were originally deposited in a highly dolomitic condition. While the variability in composition of the Lower Limestones, where

more purely marine conditions prevailed, is largely due to conditions of deposition, the Middle and Upper beds were deposited in a sea more completely isolated from the oceans, and undergoing concentration, but never complete desiccation, until perhaps the deposition of the salt-measures. This view is entirely supported by evidence deducible from the nature of the fauna.

(9) The distribution of the fauna in the Middle Limestones was largely influenced by the quantity of sulphates present in the surrounding waters in the Permian Sea. The highly fossiliferous Shell-Limestone indicates an area of comparatively sulphate-free deposition, where the fauna consequently flourished and influenced the sedimentation by its remains. The present distribution of the Shell-Limestones indicates the possibility that current-action in the Permian Sea was the determining cause of the comparative absence of sulphates.

(10) The increasing deposition of sulphates prevailing towards the top of the Shell-Limestone brought about a gradual extinction of the fauna, with a progressive dwarfing of those forms which survived, until the Uppermost Shell-Limestones yield a fauna which, though still typically Middle, yet approaches in character that of the brachiopod-free Upper Limestones.

EXPLANATION OF PLATE XXII.

Map of the Hartlepool area, showing the position of the anhydrite and the Magnesian Limestone, on the scale of three-quarters of an inch to the mile, or 1 : 84,480.

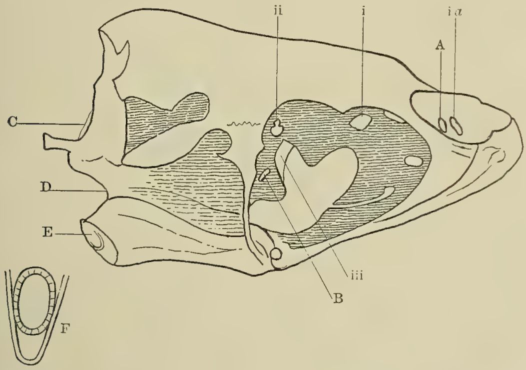
Discussion.

Dr. J. W. Evans commented on the interest and importance of the occurrence of anhydrite and gypsum in the Magnesian Limestone, either disseminated through it, or forming lenticles of various dimensions, in striking similarity to what was met with in the same formation in Germany. On the reading of Dr. Woolacott's valuable pamphlet on the rocks of Tyneside before the Geologists' Association last May, and afterwards during the excursion to that district, the speaker had insisted that the true explanation of the brecciated structure of the Magnesian Limestone in the neighbourhood of Sunderland was the former presence of gypsum, representing original anhydrite, which was afterwards dissolved out; and that the cellular and porous condition, which likewise resulted from the solution of the gypsum, favoured the formation of the concretions for which the locality is famous. In times when the rock was saturated with moisture, the excess of carbonate of lime over carbonate of magnesia would be dissolved, to be precipitated again in concretionary structures in times of desiccation; while the residue, containing lime and magnesia, approximately in the proportions of dolomite, would resist solution and remain as that fine powdery material which is found in the cavities when they are first broken open. This had been only a speculation, but the Author had shown that it was founded on fact.

12. *The* INTERNAL CRANIAL ELEMENTS *and* FORAMINA *of* *DAPEDIUS GRANULATUS, from a* SPECIMEN *recently found in the* LIAS *at* CHARMOUTH. By GEORGE ALLAN FROST, F.G.S. (Read March 19th, 1913.)

THE exterior of the skull of *Dapedius* has been described by Dr. A. S. Woodward in his paper entitled, 'The Cranial Osteology of the Mesozoic Ganoid Fishes, *Lepidotus* & *Dapedius*,' read before the Zoological Society in June 1893; but, owing to the scarcity of material available, the interior bones of the orbit and their foramina, and some other points regarding the exterior, have not yet been touched upon.

Fig. 1.—*Cranial foramina of* Dapedius granulatus. *Natural size.*



[i=Foramen for olfactory nerve; i *a*=Anterior foramen for olfactory nerve; ii=Optic foramen; iii=Exit of fifth, seventh, third, and fourth nerves; A=Foramen giving entrance to the anterior veins of the head; B=Foramen for hyoidean artery; C=Foramen magnum; D=Excavation for notochord; E=Basicranial canal; F=Section of parasphenoid and basicranial canal.]

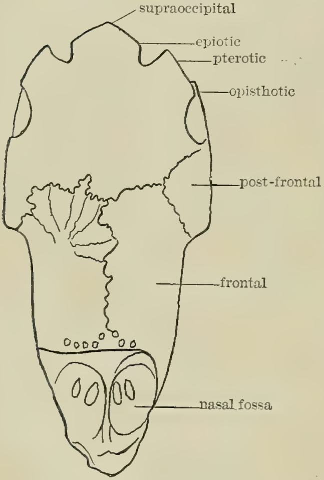
In consequence of my discovery of a very complete skull in the Lias at Charmouth, I have attempted to describe some of the points until now undetermined.

The skull was embedded in an ovoid nodule of light-coloured indurated Liassic marl, and has not been subjected to distortion by pressure, as is often the case in this formation. The nodule was lying on the foreshore between Charmouth and Lyme Regis, and had probably been washed out of the ledge known as the 'fish-bed' in

the *semicostatus* zone, where I have found other remains of Ganoids. Close to this is the 'saurian bed,' where I got at about the same time an *Ichthyosaurus tenuirostris*, which in life was probably some 7 feet long, the body of which was enclosed in a large ovoid nodule of formation similar to the smaller one containing the head of the *Dapedius*. As we know, from the undigested scales found in the coprolites of the saurians which occur here, that the Ganoid fishes formed the bulk of their food, the juxtaposition of the two is what might be expected.

Being highly pyritized, the delicate interorbital septum of the *Dapedius* is perfectly preserved, and the internal foramina admit of accurate delineation.

Fig. 2.—*Cranium of* Dapedius granulatus. *Natural size.*



As already noted by Dr. Smith Woodward, the exterior of the skull of *Dapedius* is entirely ossified, the frontals, parietals, and squamosals almost completely covering the cranium. The frontals show a radiated structure with a bold irregular suture, some ornamentation being apparent towards the anterior edges.

The entire build of the skull is massive, and eminently adapted for a strenuous existence in the Liassic seas; the heavy outer cartilage-bones are ossified throughout, and, while defended on the outside by the armoured membrane-bones, receive support internally from the arched orbitosphenoids, the whole combining to form such a covering for the brain as to offer the greatest resistance to attack.

The supra-occipital, which was visible on the exterior of the nodule when found, alone exhibits signs of erosion, exposing very clearly the formation of the bone-cells. The parasphenoid and vomer are confluent, and form a strong deeply-ridged bone, the fore part having a lateral wing for the attachment of the palatines; the vomer also shows evidences of having borne teeth.

In *Lepidotus* there is a foramen in front of the basipterygoid processes, but this is absent in *Dapedius*. In front of these processes the parasphenoid is bent sharply upwards, as already mentioned by Dr. A. S. Woodward. This inclination of the para-

sphenoid is seen in the recent *Beryx*, and, it has been suggested, has something to do with the depth of the body; *Zeus faber*, however, is an example of a deeper-bodied fish with a practically straight parasphenoid.

The basipterygoid processes are produced upwards and backwards across the anterior edges of the alisphenoids, and meet the orbitosphenoids behind their inferior projection. Between these processes is the entrance to the orbit of the basicranial canal, which lies within the posterior portion of the parasphenoid and contained the rectus externus muscles of the eye.

In *Amia calva* the canal extends for only half the distance between the orbit and the rear of the cranium, ending in a cul de sac, this being the same in *Salmo salar* and in most of the Teleostei. In *Coregonus wartmanni*, as exemplified by Vogt in his 'Embryologie des Salmones,' the canal extends to the extreme rear of the skull, and this occurs also in *Dapedius*. The truncated section of the parasphenoid shows a distinctly ossified oval chamber, which lay against the under surface of the notochord as it entered a deep conical excavation apparent in the basioccipital.

In *Amia* the canal gives entrance to the orbit to the oculomotorius, trochlearis, and ophthalmic branches of the trigeminal nerves; but in *Salmo salar* it is pierced only by the nervus abducens which supplies the rectus muscles. This statement probably holds good of *Dapedius* also, the other nerves being provided with an ample exit in a large opening immediately above, situated between the orbito-sphenoids, which probably affords a passage to the main branches of the trigeminal and facial nerves as well.

The opisthotics are stout and prominent bones inclined upwards anteriorly at a considerable angle to the basal elements of the skull, this angle corresponding with the inclination of the fore part of the parasphenoid. Posteriorly they join the exoccipitals, and anteriorly the postfrontals and alisphenoids. They are excavated below to receive the suspensorium, and in front there are depressions which gave attachment to the suborbitals.

The opisthotics on each side of the head form the floor of the temporal fossa, which, triangular behind, expands anteriorly into a circular pit. The fossa is roofed by the pterotic, and in the specimen at the British Museum (Natural History) is covered at the side by the squamosal.

A large trifoliated aperture is shown in the bony interorbital septum in conjunction with the orbitosphenoids, which, meeting at their bases, form the roof of the entrance to the basicranial canal, and again meeting in an upper and forward projection join the ethmoids.

At the superior posterior angle of the orbit on each side the orbitosphenoids are pierced by an irregularly-shaped foramen for the passage of the optic nerve; anteriorly, in conjunction with the ethmoids, they form a passage for the olfactory nerves, each of which, enclosed for the greater part of the orbit, enters it at the opening shown as i, fig. 1 (p. 219), and leaves again by the inner

foramen between the prefrontal and the ethmoid, which gives access to the nasal fossa.

In *Lepidotus* and *Amia* these nerves are entirely enclosed in canals, but in *Dapedius* they are exposed for about two-fifths of their passage across the orbit.

On the outer side of the anterior opening for the olfactory nerve is another passage between the nasal fossa and the orbit; this agrees with the orbito-nasal foramen in *Scyllium canicula*, as shown by Marshall & Hurst in their ' Practical Zoology,' through which enter the anterior veins of the head communicating with the orbital sinus.

Half way down the stout walls of the large opening between the orbitosphenoids occurs on each side a small oblique oval foramen, which probably gave access to the hyoidean artery into the cranium.

The foramen magnum is high and compressed laterally, and immediately below it the basioccipital is produced posteriorly in a process above the notochord. This process is convex above, and slightly hollowed on its inferior surface, the basioccipital on each side also exhibiting a small condyle.

The only remaining foramina to be described are those for the vagus nerves, which pierce the inferior surfaces of the exoccipitals; these are smaller openings than in *Lepidotus*, and have a more downward direction.

In conclusion, the cranium of the Ganoid *Dapedius* is shown to be more completely ossified than is the case with many Teleostei of the present day. The cartilaginous endoskeleton, as seen in *Esox* and the Salmonidæ, is replaced by true bone; and, although this may remain cartilaginous internally, there is no outward evidence that such is the case.

In preparing this paper I have received much help from the works of Dr. A. S. Woodward, F.R.S., and have also to acknowledge his kind personal assistance.

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13. *The* Fossil Flora *of the* Cleveland District *of* Yorkshire: I.—*The* Flora *of the* Marske Quarry.

By Hugh Hamshaw Thomas, M.A., F.G.S. *With* Notes *on the* Stratigraphy, by the Rev. George John Lane, F.G.S. (Read January 22nd, 1913.)

[Plates XXIII–XXVI.]

Contents.

I. Introduction.

The fossil flora of the Jurassic rocks of the Yorkshire coast has been investigated by many workers. At the beginning of last century a considerable number of the common plants were described by Brongniart and Phillips, and during the succeeding years excellent collections were made by such enthusiastic workers as Bean, Leckenby, and the two Williamsons. The close and critical study of these plants was, however, never accomplished until Prof. Seward's critical work in the British Museum Catalogue appeared. This put the subject for the first time on a firm basis, and has very much simplified subsequent investigations.

The earlier collectors confined their attention almost entirely to the accessible exposures of the Estuarine Series between Whitby and Filey, though some specimens are recorded from the neighbourhood of Runswick. In comparatively recent years, however, it has been found that the Lower Estuarine Beds in the Cleveland district were very fossiliferous, and large collections have been made by enthusiastic local geologists. As a result, several interesting forms were discovered in this district which were unknown farther south, and a systematic and critical examination of the whole flora was deemed advisable.

The present work is the result of a re-examination of the specimens collected by the Rev. G. J. Lane, F.G.S., and Mr. T. W. Saunders, F.G.S., who have succeeded in obtaining a large number of fossils from the Marske and Upleatham quarries on Upleatham Hill. They kindly sent the most important specimens in their collections to me, for examination at Cambridge. I have also had the opportunity of examining at the Dorman Memorial Museum, Middlesbrough, the collection made by the late Mr. Hawell. These existing collections have been supplemented by material which I have recently obtained from the Marske Quarry. Most of my own specimens were found in the soft grey shales in the upper part of the quarry, and are very well preserved—though somewhat fragmentary.

The species described in this paper are those that can be identified with a considerable degree of certainty. The collections mentioned above also contain specimens of other forms, which cannot at present be identified with any confidence. These must await the discovery of further material before they are described. The plants described were nearly all found at Marske. The recently discovered plants from Roseberry Topping will form the subject of a later paper.

My thanks are due to the Rev. G. J. Lane, Mr. T. W. Saunders, and Mr. F. Elgee; also to Dr. Halle, Prof. Nathorst, and especially to Prof. A. C. Seward for assistance and advice of various kinds. I am also indebted to the Marquis of Zetland for permission to excavate in the Marske quarries.

Some of the expenses incidental to the present work have been defrayed from grants made by the British Association (Committee for the Study of the Jurassic Flora of Yorkshire), and also from the Gordon-Wigan Fund of the University of Cambridge.

II. Historical Notes.

The collection of plants from the Marske Quarry seems to have been commenced by the late Rev. J. Hawell, whose specimens are now in the Middlesbrough Museum. These plants were for the most part impressions in fine-grained ironstone, and were often very well preserved. Among them were some examples of a species of *Dictyozamites*, which was described by Prof. Seward [1] in 1903. In 1909, the Rev. G. J. Lane [2] recorded the discovery of *Equisetites columnaris*, *Otozamites graphicus*, *Baiera lindleyana*, and *Zamites* sp. The same author, with Mr. T. W. Saunders, published the first complete list of species in 1909,[3] which was as follows:—

Equisetites columnaris.
*Equisetites beani.**
*Lycopodites.**
Tæniopteris major.
Tæniopteris vittata.
Sagenopteris phillipsi.
Cladophlebis denticulata.
Cladophlebis haiburnensis [*Todites williamsoni* Br.].[4]
Laccopteris polypodioides.
Base of flower of *Williamsonia.*
Fructification of *Williamsonia.*
Williamsonia gigas.
Williamsonia pecten.
Otozamites beani [? *Dictyozamites hawelli* Sew.].
Otozamites graphicus.
Otozamites parallelus [*Williamsonia pecten* Phill.].
Otozamites feistmanteli.
Nilssonia compta [*N. mediana* Leck.].
Nilssonia mediana.
Nilssonia tenuinervis [*N. orientalis* Heer].
Dictyozamites hawelli.
Ginkgo digitata.
Baiera gracilis [*B. longifolia* Pom.].
*Baiera phillipsi.**
*Baiera lindleyana.**
Czekanowskia murrayana.
*Beania gracilis.**
Araucarites sp.*
Pagiophyllum williamsoni [cf. *E. setosa*].
*Brachyphyllum mammillare.**
Cheirolepis setosus.

An asterisk (*) indicates that no conclusive evidence has been found for the existence of the species thus starred.

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[1] Q. J. G. S. vol. lix (1903) p. 217.
[2] Proc. Cleveland Naturalists' Field-Club, vol. ii, pt. 3, p. 172.
[3] 'The Naturalist' 1909, p. 81.
[4] The names in brackets are those adopted in the present paper.

In the 'Proceedings of the Cleveland Naturalists' Field-Club'[1] for 1910 the same list is given, with the addition of the following species:—

Coniopteris hymenophylloides.
Flower of *Williamsonia pecten.*
Flower of *Williamsonia gigas.*
Nilssonia schaumburgensis (Dunk.) [*N. orientalis*].

On p. 264 of the same publication the following are recorded:—

Zamites sp.
Taxites zamioides.
Nilssonia tenuicatus[2] [*N. orientalis*].
Nilssonia schaumburgensis [*N. orientalis*].
Todites williamsoni.
Zamites buchianus [*Pseudoctenis lanei*].
Pterophyllum sp.
*Cladophlebis lobifolia.**
Coniopteris hymenophylloides.

A somewhat similar list is tabulated, on pp. 15 & 16 of the 'Naturalist' for that year, by Mr. Lane and Mr. Saunders.

With the exception of *Dictyozamites*, none of the species seem to have been described, though in parts of the Cleveland 'Proceedings' referred to above, figures have been given of *Ginkgo digitata*, and plants thought to be *Zamites buchianus*, *Nilssonia schaumburgensis*, and *Cladophlebis haiburnensis*. In the present paper the chief points of interest in the various species are noticed, and those which prove to be new are dealt with in detail.

III. List of the Species described in this paper.

EQUISETALES.
- *Equisetites columnaris* Brongn.

HYDROPTERIDEÆ (?)
- *Sagenopteris phillipsi*, var. *major* Seward.

FILICES.
- *Laccopteris polypodioides* Br.
- *Dictyophyllum rugosum* L. & H.
- *Stachypteris hallei* Thomas.
- *Coniopteris hymenophylloides* Br.
- *Coniopteris quinqueloba* (Phillips).
- *Todites williamsoni* (Br.).
- *Cladophlebis denticulata* Br.
- *Marattiopsis anglica*, sp. nov.

BENNETTITALES.
- *Williamsonia spectabilis* Nathorst.
- *Williamsonia whitbiensis* Nathorst.
- *Williamsonia* sp., female strobilus.
- *Zamites (Williamsonia) gigas* L. & H.
- *Ptilophyllum (Williamsonia) pecten* (Phillips).
- *Tæniopteris vittata* Br.
- *Tæniopteris major* L. & H.
- *Tæniopteris* sp.
- *Wielandiella (Anomozamites) nilssoni* (Phillips).
- *Otozamites feistmanteli* Zigno.
- *Otozamites graphicus* (Leckenby ex Bean MS.).
- *Dictyozamites hawelli* Seward.
- Cycadean stem, cf. *Wielandiella* sp.

CYCADALES (?)
- *Nilssonia mediana* (Leckenby ex Bean MS.).
- *Nilssonia orientalis* Heer.
- *Pseudoctenis lanei*, sp. nov.

GINKGOALES.
- *Ginkgo digitata* (Br.).
- *Baiera longifolia* (Pomel).
- *Czekanowskia murrayana* (L. & H.).

CONIFERALES.
- *Elatides* sp. cf. *E. setosa* (Phill.).
- *Taxites zamioides* (Leckenby ex Bean MS.).

[1] Vol. ii (1910) pt. 4, p. 206.
[2] Probably a misprint for *tenuinervis*.

IV. Description of the Species.

(i) PTERIDOPHYTA.

Equisetales.

Equisetites columnaris (Brongn.).

['Hist. Végét. Foss.' 1828, p. 115 & pl. xiii.]

This species is represented by several sandstone casts of parts of leafy shoots. These are mostly about 3 cm. in diameter, and show the usual leaf-sheaths at the nodes, with united leaves about 2 cm. long, but becoming free at the tips. A sandstone cast of a single leaf-sheath in Mr. Saunders's collection has a diameter of about 4 cm., and evidently belonged to a very large stem. The leaves are about 2 mm. broad, and show at their bases cushion-shaped structures, perhaps representing part of the cortex, and somewhat similar to those recently figured by Prof. Seward from Afghanistan.[1]

I have seen no specimen from Marske that can be identified with certainty as *Equisetites beani*, but good examples of the latter occur frequently at Roseberry Topping.

Hydropterideæ (?).

Sagenopteris phillipsi, var. major Seward. (Pl. XXV, fig. 2.)

['Jurassic Flora Yorks.' Brit. Mus. Catal. vol. i (1900) pp. 162, 169 & fig. 26.]

A number of separate leaflets have been found which are of an unusually large form. Several of the incomplete specimens are 5 cm. long, and one of them is 7 cm. long and 4 cm. broad (see Pl. XXV, fig. 2). There is a well-marked midrib, though in a few cases this is not conspicuous, and the venation is of the usual anastomosing character. The venation is coarser than that usually seen in *S. phillipsi*. The specimen here described may be compared with the examples figured by Prof. Seward.

Filices.

Laccopteris polypodioides (Brongn.).

['Hist. Végét. Foss.' 1828, p. 372 & pl. lxxxiii, fig. 1.]

This species is represented by a few small fragments of fertile pinnules found in the grey clays and sandstone. They show the usual characters of this form. The sori are arranged in two rows, one on each side of the midrib. The individual sporangia are not seen; this may be an indication that they were covered with an indusium. The veins are clearly seen, but do not show the usual anastomosing. I have found many fragments similar to

[1] Seward (12) pl. i, figs. 6, 7, & 9. The numerals in parentheses refer to the Bibliography, § VI, p. 248.

these on the coast between Cloughton Wyke and Hayburn Wyke; the species is also common at Gristhorpe.

DICTYOPHYLLUM RUGOSUM Lindl. & Hutt.

['Foss. Flor.' vol. ii (1833-35) pl. civ.]

This species is represented by some small fragments of fronds found in the grey shale. These fragments show parts of the lobed frond-segments with anastomosing venation of the usual type, and are very characteristic.

STACHYPTERIS HALLEI Thomas.

[Proc. Cambridge Phil. Soc. vol. xvi (1912) p. 610.]

I obtained in the grey shale a few good examples of this fern, which previously was only known from a single specimen found by Dr. Halle at Whitby. They show some young fertile portions in which the sporangia are apparently covered with scale-like indusia, and yielded the characteristic reticulate spores. Reference may be made for details of this form to the description which I have recently published.[1]

CONIOPTERIS HYMENOPHYLLOIDES (Brongn.).

['Hist. Végét. Foss.' 1828, p. 189 & pl. lvi, fig. 4.]

Many fragments of fronds of this species have been found. Some of them are badly preserved, but others show clearly the usual characters of this common form. In the grey shales a fragment of a fertile pinna has been found, which shows *Tympanophora* characters and may have belonged to this species.

CONIOPTERIS QUINQUELOBA (Phillips).

['Illustr. Geol. Yorks. pt. 1—The Yorkshire Coast' 3rd ed. (1875) p. 215.]

The identification of finely-divided fronds of the *Coniopteris* type is a matter of considerable difficulty at present. Phillips described and figured two forms as *Sphenopteris quinqueloba* and *Sph. arbuscula*, which apparently are closely allied[2]; but the fertile fronds of these forms are not definitely known. The pinnules of *C. hymenophylloides* are very polymorphic, and the finely-divided foliage may even be a form of this species. In the present case I have found in the grey shales several small portions of tripinnate or quadripinnate fronds with very finely-divided segments well preserved. These may be provisionally associated with *C. quinqueloba*, although the possibility of their being sterile fronds of *Stachypteris hallei* must not be overlooked. They are, however, more finely divided than the fertile fronds of the latter, and it is usually the lamina of the fertile fronds which is the more reduced.

[1] Thomas (12[2]).
[2] Seward (00) p. 112.

Todites williamsoni (Brongn.). (Pl. XXIII, fig. 6.)

['Hist. Végét. Foss.' 1828, p. 324 & pl. cx, figs. 1–2.]

This form is represented by fragments of pinnæ closely set with pinnules. The axes of the pinnæ are in most cases broad, the pinnules somewhat falcate, and in several specimens of a large size (12 mm. long). The nervation is often clearly seen, and is of the usual type, the secondary veins being mostly twice dichotomized (see Pl. XXIII, fig. 6). No fertile specimens are seen, but I have recently obtained sterile and fertile pinnæ from Gristhorpe which have precisely the same form and venation as the examples here described. Fertile pinnules of this longer form in the British Museum have been also figured by Prof. Seward.[1]

Cladophlebis denticulata (Brongn.).

['Hist. Végét. Foss.' 1828, p. 301 & pl. xcviii, figs. 1–2.]

A number of fragmentary specimens have been obtained which undoubtedly belong to this species, although no very complete examples have been found. Most of the pinnæ are rather small, falcate, and with once-bifurcated veins. One example shows the apical portion of a frond, the pinnæ of which are set with short, acute, contiguous pinnules which have secondary veins once bifurcated or simple.

Marattiopsis anglica, sp. nov. (Pl. XXIII, figs. 1–5.)

No specimens referable to the genus *Marattiopsis* have been hitherto described from Yorkshire.[2] It is, however, a very common Rhætic and Liassic form, and has been recorded from Sweden, Bornholm, Germany, Poland, and Tongking.[3] Recently two incomplete leaflets from the Jurassic (Kimmeridge) beds of Sutherland have been placed by Prof. Seward in this genus.[4] Allied forms from the Jurassic of Oregon have been described by Lester Ward and others under the old name of *Angiopteridium*.[5]

A number of sterile and fertile pinnæ (or pinnules) have been found at Marske; but, in some of the plant-beds at Roseberry Topping, they are extremely abundant, and formed in fact one of the characteristic features of the vegetation.

Most of the specimens are preserved in a fine-grained micaceous sandstone, and consequently many details of their form are obliterated; some portions of pinnæ have, however, been obtained from the finer-grained shales and ironstone. All the specimens found are portions of linear pinnæ, having a width of 14 to 22 mm. and a considerable length. The total length of a complete pinna is unknown, but pieces about 30 cm. long have been obtained. The apex probably was bluntly rounded, as seen in the apical

1 Seward (00) p. 94, fig. 12.
2 Seward (00) p. 309.
3 Zeiller (02) p. 63.
4 Seward (11) p. 670 & pl. ii, figs. 28–29.
5 Ward (05) pl. lxvi.

portion of a small pinna. The base is seldom seen, but in a specimen collected by Mr. H. T. Kennedy, Trinity College, Cambridge, a portion of the rachis (or pinna-axis) is seen still attached to the pinna-base (Pl. XXIII, fig. 1); the lamina is not well preserved, but the rachis is 3 to 4 mm. thick. The pinnæ were probably attached to the rachis at right angles; but their base is not clearly seen, and so it is impossible to say whether it was of the unequally cordate type seen in *M. hœrensis* or of the more rounded form seen in *M. münsteri*. In so far as can be made out from other specimens, the bases of the pinnæ were unequally rounded, and approximate rather to the form seen in *M. münsteri*. Each pinna had a stout mid-vein 1 to 3 mm. broad, and bearing fine striations. The secondary veins spring from this: they are about 1 mm. apart, and run out nearly at right angles to the margin, but are more oblique near the apex of the pinna. They are fine, and are often bifurcated near the mid-vein (Pl. XXIII, fig. 2): some of them appear to be simple; but the forking of the veins is often obscured, owing to the close proximity of the mid-vein. The margin of the lamina is entire.

In some of the impressions each vein appears as if it were considerably swollen: this is due to the presence of linear synangia above the veins (see Pl. XXIII, fig. 3). Each synangium appears to have projected somewhat above the surface, and to have had a fairly firm wall enclosing a number of loculi arrranged in two rows; each loculus probably formed a projection, and imparted to the synangium a corrugated appearance (Pl. XXIII, fig. 5). The length of the synangia is usually considerable: they often occupy most of the space between the midrib and the margin, and may be about 7 mm. long; but in other specimens they are shorter (4 mm.), and approach *M. hœrensis* in this respect (Pl. XXIII, figs. 4 *a* & 4 *b*). When portions of the synangia are treated with Schultz's solution they yield a membrane of fairly thick cells, and therefore were probably firm in texture.

Fig. 1.—*Spores of* Marattiopsis anglica. × *300.*

On some of the remains of synangia being removed and treated in the usual way,[1] it was possible to make out the form of some of the spores. The latter, however, were not obtained in large quantity, owing partly to the thickness of the synangium-wall, and perhaps to the age of the synangia when preservation took place. The spores exhibit some features of interest (see fig. 1): they are rather small, measuring only about ·03 mm., and are rather spherical though flattened on one side. Their walls appear to be densely covered

[1] For methods, see Thomas (12[1]) p. 109.

with small projections which give them rather a roughened aspect. The usual tetrad scar is not seen on any example, but a single straight scar instead, which doubtless indicates that the spores were arranged in the spore mother-cells bilaterally and not tetrahedrally.

The genus *Marattiopsis* has not yet received very critical study. Schimper, under the old generic name of *Angiopteridium*,[1] distinguished a number of species which, according to his account, do not appear to differ very markedly one from the other. The most definite are perhaps *M. münsteri* (the common Rhætic form) and *M. hœrensis* from the Hör Sandstone (Liassic) and other beds in Scania. The latter species differs from the common form in the possession by the pinnæ of an obliquely-cordate base, and also in having longer synangia.

The specimens now described are nearly allied to the abovementioned species, but approach closely to *M. hœrensis* in the size of the pinnæ and the length of the synangia; they do not, however, appear to possess the obliquely-cordate base of the Swedish species. At the same time, in many of the Yorkshire examples the synangia are markedly different in size from those of *M. hœrensis* and still more from those of *M. münsteri*. They are much elongated, and extend across from the margin almost to the midrib.

This character, together with the shape of the bases of the pinnæ, is probably sufficient to warrant the separation of the English specimens from the Rhætic type, and hence I have introduced the name of *anglica* for the species just described.

(ii) GYMNOSPERMÆ.

Bennettitales.

WILLIAMSONIA SPECTABILIS Nathorst. (Pl. XXIV, figs. 1 *a*–3.)

['Palæobot. Mitt. 9' K. Svenska Vetensk.-Akad. Handl. vol. xlvi (1911) No. 4, p. 5 & pl. i, figs. 1-11.]

Male sporophylls, identical with those described by Prof. Nathorst from Whitby, are not uncommon at Marske. There are two or three good specimens in the Riksmuseum at Stockholm, which were collected by Dr. Halle and Prof. P. F. Kendall. Reference is made to one of them in the original description,[2] and a still better specimen is figured here (see Pl. XXIV, fig. 2). The latter example[3] shows parts of two sporophylls, bearing several of the characteristic synangia: these are situated at right angles to the length of the sporophyll, and have the appearance of being borne on short projecting branches. In 1911 I collected an interesting but still fragmentary specimen (see Pl. XXIV, fig. 1 *a*). The base of the cup

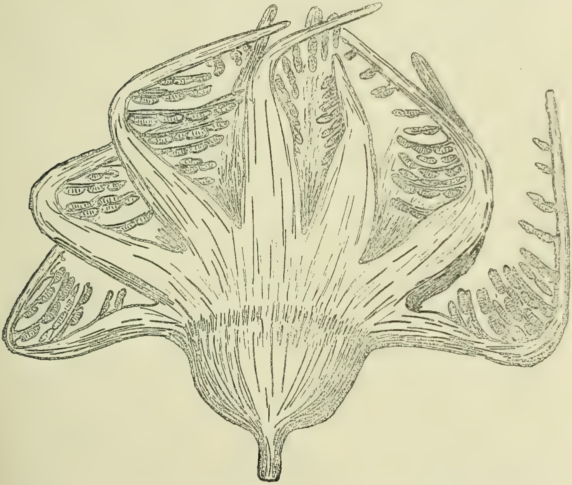
[1] Schimper (69) p. 603 & pl. xxxviii.

[2] Nathorst (11) p. 8.

[3] [Since this paper was written, this specimen has been figured and fully described by Prof. Nathorst (12[2]). Special emphasis is laid on the indications that the fertile branches or pinnæ were produced from the midrib, and not from the margins of the sporophylls.]

is not seen, but the greater part of three sporophylls is preserved. This flower was evidently of considerable size, like the original Whitby specimen; its shape can be made out from the figures. On becoming free the sporophylls appear first to spread upwards fo about 4 cm., and then curve round and run in a more or less horizontal direction for another 5 or 6 cm. In a living condition these elongated ends of the sporophylls would probably arch over the centre of the cup, although they may have straightened out at maturity. In the original examples the arching-over of the tips of the sporophylls was seen, but they only appeared to project inwards for less than a centimetre, and seemed to have rather a circinate shape. The breadth of the sporophylls is

Fig. 2.—*Restoration of an almost mature male flower of* Williamsonia spectabilis *Nathorst. About natural size.*



about 13 mm. when they become free: it would appear to decrease to about 7 mm. near the bend, and may be about 4 mm. near the tip; but, as the margins are probably more or less folded together towards the tips, their exact breadth is somewhat difficult to determine. In the example before us the synangia lie on the concave side of the sporophyll. They are of the same form as in the Whitby examples, and lie in regular rows with their long axes at right angles to the sporophylls. Near the bases of the sporophylls only a few single synangia are seen; higher up they appear to be in rows of two; and towards the angle where the free limb

bends over they seem to lie in rows of four or five, but decrease again in number on the terminal over-arching parts.

The synangia of each row appear to have been borne on slender stalks which are sometimes seen, but the sandy nature of the matrix makes the structure rather indefinite in places. These stalks seem to have been given off on each side of the central portion of the sporophyll, and may be regarded either as lateral lobes of this organ, or possibly as arising as part of a pinnate structure like the microsporophyll of *Bennettites*, which is adnate with the broad structures hitherto termed sporophylls. The examination of the specimens favours the former view, but in few cases is the origin of the synangium-bearing branches clearly seen. The latter view is not based on any actual evidence, but may be advanced to homologize the present structure with the American specimens of *Bennettites*, where whorls of free bracts occur outside the narrow segments of the microsporophylls. Though the attachment of the lateral branches to the sporophyll is not very clearly seen, in some places they seem to be given off from the centre of the sporophyll. In other places (see Pl. XXIV, figs. 1 *a* & 1 *b*) they appear as slight projections on the side of the main sporophyll at intervals of about 7 mm., but are seldom sufficiently definite to be considered as more than indications of the structure. In one case, however, near the apex of a sporophyll the projection is of the nature of a small lateral lobe about 7 mm. long, rounded at the end and bearing one or two synangia (see Pl. XXIV, fig. 1 *b*).

The synangia appear to be produced on each side of some of these lateral segments. By careful dissection of part of the sporophyll, it would seem probable that towards the apex the inward projecting lobes occurred on both of its margins.

Whatever may have been the method of production of the synangia of *Williamsonia spectabilis*, this form serves (as Prof. Nathorst believes) as a valuable connecting-link between the type of microsporophyll seen in *Bennettites* (*Cycadeoidea*), where the sporophyll is a reduced pinnate structure, and the *Williamsonia-whitbiensis* type, where the sporophyll is undivided, and bears a double row of synangia on its surface. The latter type is also seen in *Weltrichia* and *Cycadocephalus*[1] according to Prof. Nathorst, and in my new Yorkshire form *Williamsoniella*. A rather curious impression has also been found in the sandstone, which is of the form shown in fig. 3 (Pl. XXIV). We can only form a conjecture as to the nature of this structure, but it appears to have probably been a separate young microsporophyll of a 'flower' of the type described above. The projecting lobes of the sporophyll are well seen, but no indications of synangia can as yet be made out. The occurrence of this single sporophyll, if such be its nature, leads us to wonder whether the sporophylls could have been free when young and have become united when older.

[1] Nathorst (12^1) p. 10.

WILLIAMSONIA WHITBIENSIS Nathorst.

[' Palæobot. Mitt. 9' K. Svenska Vetensk.-Akad. Handl. vol. xlvi (1911) No. 4, p. 9, & pl. ii, figs. 1–15, pl. iii, figs. 2–7.]

The presence of this type of 'flower' in the Marske beds is rendered probable by the examination of a crushed and rather badly-preserved specimen in my collection. The cup-like base of the 'flower' is seen and was apparently sessile, but the free portions of the sporophylls cannot be clearly made out. At intervals, however, we can distinguish double rows of depressions running upwards and occupying the positions in which we should expect to find the sporangia. There seems to be little doubt that these double rows of depressions (or in some cases elevations) represent the original synangia (functional or reduced), but the specimen is not sufficiently well-preserved for us to be certain of the details of structure. The cup of the flower would probably be about 4 or 5 cm. across, and it is thus considerably smaller than that of *Williamsonia spectabilis*. There seems to be little reason to doubt that this is a specimen of *Williamsonia whitbiensis* Nathorst.

WILLIAMSONIA sp. Female strobilus.

A single specimen of a female strobilus has been found in the grey shales. Its outline is very indefinite, and the point of attachment cannot be clearly made out. It is roughly circular, and at one side the scales show an elongated shape probably indicating proximity to the base. The whole structure is composed of a mass of well-defined hexagonal bodies, the heads of the interseminal scales. These were apparently of a firm, if not woody, texture and stand out clearly; no traces of micropylar tubes are seen between them. When some of the scales are removed and treated with Schultz's solution, a certain amount of the structure becomes visible. The heads of the scales seem to be composed of a number of cells having very thick walls, and displaying a roughly radial arrangement. The arrangement of the cells is, however, not so regular as in the examples of *Williamsonia leckenbyi* (*pecten*) figured by Prof. Nathorst[1]; the cells are also more strongly thickened than in that form.

The absence of micropylar tubes and the strongly thickened nature of the scales suggest that this was possibly an old strobilus from which the micropylar tubes had disappeared after fertilization. In the absence of further details of structure it is impossible to assign to the specimen any specific name. No definite male strobili have been found in the same bed, but some portions of male sporophylls of apparently a new type have been found. The latter are not yet sufficiently known to merit description in this paper.

Other fragmentary examples of Bennettitalean strobili have also been found in the sandstones.

[1] Nathorst (09^2) pl. iii, figs. 8–10.

ZAMITES (WILLIAMSONIA) GIGAS (Lindl. & Hutt.).

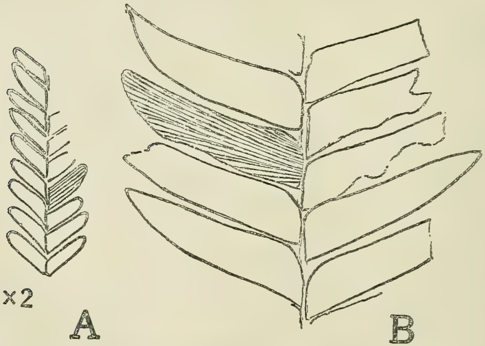
['Foss. Flor.' vol. iii (1837) pl. clxv.]

Two specimens of fronds occur in Mr. Lane's collection that can be referred to this species. They show a rachis, on the upper side of which numerous pinnæ are closely set. The pinnæ are lanceolate in shape, with entire margins tapering gradually to an acuminate apex. Their bases are rounded, and they are attached to the rachis by the central portion of the base, which is slightly concave in form at the point of insertion. The pinnæ are traversed by a number of fine parallel veins.

One of the specimens is part of a larger frond, with pinnæ 8 to 9 cm. long and attaining a width of about 13 mm.; the other more complete example has much smaller pinnæ, only 2 cm. long and 5 mm. wide. The characters of both specimens are, however, identical: most probably both belonged to the same species, which occurs frequently at Whitby, Gristhorpe, and other localities in Yorkshire.

Another large and typical example is in the collection made by the late Mr. Hawell, preserved in the Middlesbrough Museum. The large form also occurs at Roseberry Topping.

Fig. 3.—*Outlines of portions of two types of fronds referable to the aggregate species* Ptilophyllum (Williamsonia) pecten.



[A is magnified 2 diameters; B is of the natural size.]

PTILOPHYLLUM (WILLIAMSONIA) PECTEN (Phillips).

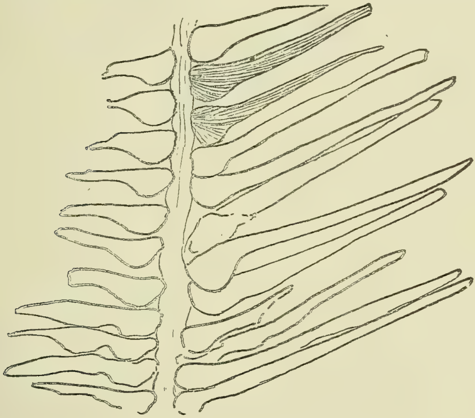
['Illustr. Geol. Yorks. pt. 1—The Yorkshire Coast' 1829, p. 148 & pl. vii, fig. 22.]

In most of the Yorkshire fossil-plant localities series of fronds are found which show a considerable range of variation among themselves, but are all referable to the type of *Pt. pecten*. The

collections here described contain a similar large series of fronds which are, for the present, all included under this species. Several well-marked varieties occur; but, as at Whitby,[1] they seem to be connected one with the other by intermediate forms. It is probable that future work on the structure of the cuticles of these forms[2] will show that the principal varieties may be regarded as distinct species. I hope to undertake the detailed investigation of this question, when further specimens have been obtained in a suitable state of preservation.

The form and nervation of some characteristic pinnæ are shown in figs. 3 & 4. The pinnæ are for the most part attached to the

Fig. 4.—*Another type of frond of* Ptilophyllum (Williamsonia) pecten, *showing the basal lobes of the pinnæ. Natural size.*



rachis by a broad portion of their bases. In some of the larger examples, there is a well-marked basal lobe on the lower (see fig. 4) or upper margin; specimens showing the latter characteristic approach nearly to the *Otozamites* type, while the *Ptilophyllum* type is the commonest (see fig. 3, p. 234). A more detailed consideration of the group is reserved for a future occasion.

Tæniopteris vittata Brongn.

['Hist. Végét. Foss.' 1828, p. 263 & pl. lxxxii, figs. 1–4.]

This very common Yorkshire fossil is represented at Marske by a number of specimens showing the usual form and bifurcating

[1] See Seward (00) p. 190.

[2] The epidermis of the fronds of the type shown in fig. 3 B (p. 234) was thickly covered with circular hair-scars.

venation. No complete specimens are present in the collections here described, but the width of the fronds varies from 15 to 40 mm. As usual, there is considerable variation in the number and in the method of forking of the veins, but the distance between them never seems to exceed more than ·75 mm. The apex is seen to be retuse. Some of the specimens are preserved in the grey shale; and, of the cuticles of these, excellent preparations have been obtained, which show the following features. The stomata are found only on the lower side, where they are very numerous and seem to be irregularly scattered: they consist of two small brownish guard-cells, slightly sunk below two large clearer lateral cells. The walls of the epidermal cells exhibit a very sinuous outline, similar to that seen in the fronds of *Williamsonia* and *Dictyozamites.* Numerous irregular papillæ or hairs are seen on the lower epidermis. The upper epidermis is composed of a homogeneous layer of cells with rather thicker walls, presenting the same very sinuous outline. The margins of some of the fronds are seen to be slightly crenulate. The epidermal characters of these fronds agree closely with those from Gristhorpe and Cloughton, but the latter seldom possess papillæ.

Tæniopteris vittata has hitherto been usually regarded as the frond of a fern; but, owing to the form of the cuticle, I believe that it is really the frond of a Bennettitalean plant. I hope to deal more fully with this subject in a forthcoming paper.

TÆNIOPTERIS MAJOR Lindl. & Hutt.

['Foss. Flor.' vol. ii (1833–35) pl. xcii.]

Several specimens have now been found, of broad *Tæniopteris*-like fronds with a very coarse venation. The most complete example, from Mr. Saunders's collection, is about 15 cm. long, and represents the upper part of a frond. It is 5 cm. broad, and narrows towards the apex, the tip being apparently rounded. The midrib is narrow (1 mm.); the veins are somewhat crowded and numerous, being given off at right angles to the midrib. They bifurcate once or twice on their way to the margin. Other specimens collected by the late Mr. Hawell, and now in the Middlesbrough Museum, show portions of similar broad fronds. These are over 6 cm. broad, have a narrow midrib (1 mm. or less), and lateral veins given off nearly at right angles. The latter arise at intervals of 1 to 1·8 mm., and bifurcate at varying distances from the midrib; they are usually twice bifurcated, and near the margin the ultimate divisions are rather more than 0·5 mm. apart.

These specimens may be compared with the figure of *Tæniopteris major* given by Lindley & Hutton; apparently they are sharply marked off from the ordinary type of *T. vittata* by the breadth of the lamina, and by the very coarse venation. By comparison with other Yorkshire specimens, however, many transitional forms may be observed; and it may be that *T. major* ought only to be regarded as a variety of the more abundant type.

TÆNIOPTERIS sp.

Another specimen shows a fragment of the apical part of a frond. It is well preserved, and shows a characteristic irregularly-crenate or lobed margin. The apex again is not clearly seen, but seems to have been very obtuse. The midrib is rounded, and is about 1·5 mm. broad. The venation is characteristic. The veins are crowded, and present a doubled appearance, owing to the presence of a groove down the centre of each rather broad lateral vein. They arise at intervals of 1 mm., but bifurcate almost at their point of origin. They often fork again after an interval of 1 or 2 mm.; but this second division may take place farther out, or not at all. The resulting appearance is that of a large number of stout veins running almost parallel and closely crowded: near the margin about twenty-four veins occur in each centimetre. This type of frond is again quite distinct from the common form of *T. vittata*; but, in the absence of further and more complete specimens, its relationships need not be further discussed.

WIELANDIELLA (ANOMOZAMITES) NILSSONI (Phillips).

['Illustr. Geol. Yorks. pt. 1—The Yorkshire Coast' 1829, p. 147 & pl. viii, fig. 4.]

This species, which has hitherto been recorded chiefly from the Middle Estuarine Beds near Scarborough, occurs at Marske, and also at Roseberry Topping. In both places portions of its very characteristic fronds have been found, which agree closely with those previously described under the name of *Anomozamites nilssoni*.[1] Prof. Nathorst[2] has discovered fronds which are very closely allied to these, in connexion with stems and characteristic flowers, and has given the new generic name of *Wielandiella* to them. I believe that we are perfectly justified in applying this name to our Yorkshire specimens, though we have not yet discovered their flowers. This view is further strengthened by the discovery of stems at Marske which are very similar to the stems of the Swedish plant, although we have as yet no evidence of the connexion of these stems with any fronds.

Cuticular preparations have been obtained from the Marske specimens, and show characters which I regard as typical of the Bennettitalean fronds.

OTOZAMITES FEISTMANTELI Zigno.

['Flor. Foss. Oolit.' vol. ii (1885) p. 90 & pl. xxxiv, figs. 6–8.]

Prof. Seward in his 'Jurassic Flora' employs this name for long, narrow, linear fronds of the Otozamitean type. This type is represented at Marske. The fronds have a length of 15 to 20 cm. or more, and a breadth of about 1·6 cm. The short blunt pinnæ are arranged at right angles to the rachis, are placed on its upper side,

[1] Seward (00) p. 204 & text-fig. 36.

[2] Nathorst (02) pl. i, figs. 26–35, pl. ii, figs. 1–31, & pl. iii; also Nathorst (09^2) p. 22.

and have the characteristic auriculate bases. The adjacent pinnæ overlap. The apices are bluntly pointed, and the venation is of the usual spreading type.

These fronds do not differ very much, except in size, from some forms of the commoner species *graphicus*; the pinnæ are, however, more crowded, are more perpendicular to the rachis, and their apices are blunter. It is probably best, therefore, to distinguish them as a separate species.

Otozamites graphicus (Leckenby *ex* Bean MS.).

[Q. J. G. S. vol. xx (1864) p. 78 & pl. viii, fig. 5.]

The commoner form of *Otozamites* possesses fronds about 5 cm. broad, with closely-set pinnules. The latter overlap at their bases, which have a well-marked auriculate shape. Their lower margins are markedly curved, while the upper margins are much straighter; consequently the pinnæ do not exhibit so falcate a shape as is usual in this species. The apices are acuminate, and directed slightly forward; the nervation has the usual spreading character.

The Marske form is intermediate between *O. graphicus* and *O. obtusus* var. *ooliticus* Sew. The pinnæ bear considerable resemblance to the latter variety in their shape, but have acuminate apices differing entirely in form from those of *O. obtusus*; the upper lobe of the base is also larger than in the latter. Some of the specimens resemble very closely the example figured by Prof. Seward[1] on pl. ii of the 'Jurassic Flora'; but they seem to indicate that the distinction between *O. graphicus* and *O. obtusus* var. *ooliticus* is very slight.

Other specimens of *Otozamites* have been found, which are intermediate between the above species and certain forms of *Ptilophyllum (Williamsonia) pecten*; the pinnæ are narrow, almost straight, and linear-lanceolate. They have acuminate apices and well-marked overlapping auriculate bases. They may possibly belong to a distinct species, but their differences scarcely seem such as to warrant their separation from the above.

Dictyozamites hawelli Seward.

[Q. J. G. S. vol. lix (1903) p. 221.]

The collections here described contain a large number of specimens of the above species, which is evidently one of the most abundant forms found in this locality. The species was founded in 1903 by Prof. Seward on specimens from the Marske Quarry, and there is little to add to the description then given of them. The portions of fronds before me vary in width from 4 to 9 cm., and taper gradually towards the apex. Isolated pinnæ are found in the grey shales, and from them good cuticular preparations can be obtained. In these it is seen that the upper epidermis bears no stomata, but consists of cells with very sinuous walls; the cells

[1] Seward (00) pl. ii, fig. 6.

over the veins are more elongated than the intermediate cells. Numerous stomata are seen on the lower side, which has an extremely delicate cuticle: here again the cells have very sinuous walls, and are affected by the position of the veins. The stomata are produced between the veins, and have two rather spindle-shaped guard-cells and two subsidiary cells. These cuticles are almost identical with those of *Dictyozamites johnstrupi* from Bornholm described by Prof. Nathorst [1]; but the papillæ, which are so characteristic of that form, are not conspicuous here, and seem to be absent from most cells, although a small central dot can sometimes be made out.

Cycadean Stem, cf. Wielandiella sp.

In the collection of Mr. Saunders, and also among the plants from Marske at the Naturhistoriska Riksmuseum in Stockholm, there are specimens showing the remains of stems which remind one of the stems of *Wielandiella* that Prof. Nathorst described.[2] The original stems seem to have measured about 1·7 cm. across, and occasionally bifurcate into two portions which, however, did not lie in the same plane. At the point of bifurcation another depression is seen, possibly corresponding to another branch in a plane at right angles, but, owing to its rather small size, more probably representing the exit of a floral axis. No signs of flowers or leaves are found; but below the bifurcation a number of somewhat rounded irregular markings are seen, representing the leaf-scars. Nothing can be made out for certain as to the form of these scars, but they seem to be almost absent from the branches just above the point of bifurcation. In the latter region fine markings are seen running transversely across the stem-cast at more or less regular intervals, though it is not clear what they represent.[3] In the lower parts of the stem the cast has a somewhat irregularly-wrinkled surface.

While nothing can yet be said for certain as to the real nature of these stems, it is of some interest to note their occurrence in a bed containing many Cycadean fronds, as also their similarity to the stems of *Wielandiella*. It is to be hoped that further collections may elucidate their nature.

Cycadales (?).

Nilssonia mediana (Leckenby *ex* Bean MS.).

[Q. J. G. S. vol. xx (1864) p. 77 & pl. viii, fig. 2.]

This form, which has hitherto been recorded chiefly from the Middle Estuarine Beds of the Scarborough district, seems to be well represented at Marske.

[1] Nathorst (07) p. 12 & pl. iii, figs. 2–8.
[2] Nathorst (02) p. 9 & pl. ii, figs. 1–31; also pl. iii.
[3] Prof. Nathorst figures similar transverse striations on some of the stems of *Wielandiella*; see Nathorst (02) pl. ii, figs. 2, 5, 10, & 20.

The specimens are rather fragmentary, but show fronds which are divided to the rachis into segments of somewhat unequal breadth. Fine simple parallel veins traverse the segments, two or three occurring in each millimetre.

The specimens in the present collection tend to fall into two groups: some having short truncated segments 10 to 25 mm. long, while the others have long linear segments 40 to 60 mm. in length. When these specimens, however, are compared with examples from other Yorkshire localities, it is seen that all variations in form occur between similar limits. The smaller specimens may represent young fronds, or the basal portions of larger ones. In one example the latter is obviously the case. The longer segments, while having in the main the same type of venation as the shorter, show a longitudinal wrinkling of the lamina which gives the appearance of a much coarser venation. The same segments also show the characteristic expanded approximating bases, as figured by Prof. Seward [1] for this species.

One fragment of a frond was found in the grey shales, but the cuticle appears to be very thin, and it was not possible to make large preparations of it. The fragments which were obtained showed, however, that the epidermal cells were of the rectangular form seen in *Nilssonia polymorpha* and *N. brevis*.[2]

Some excellent specimens, showing fronds of all sizes, have been collected from Roseberry Topping by Mr. H. T. Kennedy. The smaller fronds have a breadth of about 12 mm., while the larger examples must have measured more than 16 cm. across. They exhibit characters similar to those of the Marske specimens, and are chiefly remarkable for their size.

NILSSONIA ORIENTALIS Heer. (Pl. XXIII, fig. 7 & Pl. XXV, fig. 1.)

1878. *Nilssonia orientalis*, Heer, 'Flor. Foss. Arct.' vol. v, No. 2, p. 18 & pl. iv, figs. 5–9.
1880. *Nilssonia tenuinervis*, Nathorst, 'Berättelse' Öfvers. K. Svenska Vetensk.-Akad. Förhandl. No. 5, p. 35.
1882. *Nilssonia johnstrupi*, Heer, 'Flor. Foss. Arct.' (Flora der Ataneschichten') vol. vi, p. 44 & pl. vi, figs. 1–6.
1889. *Nilssonia orientalis*, Yokoyama, Journ. Coll. Sci. Tokyo, vol. iii, pl. xiv, figs. 4–9.
1897. *Nilssonia* sp. cf. *orientalis*, Nathorst, 'Mesoz. Flor. Spitzbergens' K. Svenska Vetensk.-Akad. Handl. vol. xxx, No. 1, pl. i, fig. 18.
1900. *Nilssonia tenuinervis*, Seward, Proc. Manchester Lit. & Phil. Soc. vol. xliv, No. 8, p. 4.
1900. *Nilssonia tenuinervis*, Seward, 'Jur. Flor. Yorks.' vol. i, p. 230 & fig. 41.
1905. *Nilssonia orientalis*, Fontaine & Ward, U.S. Geol. Surv. Monogr. vol. xlviii, pl. xvi, figs. 3–9.
1909. *Nilssoniopteris tenuinervis* (pars), Nathorst, K. Svenska Vetensk.-Akad. Handl. vol. xliii, No. 12, pl. vi, figs. 23 & 24.
1911. *Nilssonia orientalis*, Seward, Trans. Roy. Soc. Edin. vol. xlvii, pt. 4, p. 695 & pl. iv, figs. 60, 63–65; pl. ix, figs. 34, 40, 42.
1911. *Nilssonia orientalis*, Thomas, Mem. Com. Géol. Russ. n. s. No. 71, pl. vii, fig. 1.

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[1] Seward (00) pl. iv, fig. 1.
[2] Nathorst (09 [1]) pl. vii, figs. 14–15 & pl. viii, figs. 1–18.

The species *Nilssonia orientalis* was founded by Heer in 1878 for specimens from Siberia characterized as follows:—

'*N. foliis integris vel vario modo incisis, nervis numerosissimis subtilissimis, costulis omnino obsoletis.*' (*Op. supra cit.* vol. v, No. 2, p. 18.)

Two years later Prof. Nathorst described as *N. tenuinervis* some linear fronds which often exhibited irregular lobes, and had been found in Yorkshire. Subsequently Prof. Seward adopted this name for Yorkshire specimens at Manchester and the British Museum. He only found a few specimens in these collections, and noticed that they may be compared with Heer's species. In 1909 Prof. Nathorst re-examined his specimens, came to the conclusion that they showed affinities with the ferns, and proposed for them the new generic name of *Nilssoniopteris*. A further examination of the specimens in the Stockholm Museum, and also of a number of examples collected by myself in Yorkshire, has convinced me that Prof. Nathorst had included some fronds of *Tæniopteris vittata* among the specimens which he studied, and that it was largely on the evidence derived from the latter that his conclusions were based. It is often very difficult to distinguish between specimens of *Tæniopteris* and this *Nilssonia*; but, while the former show the supposed fern-like characters, the latter is a true *Nilssonia*. I was able to show my preparations to Prof. Nathorst, and he agreed with the conclusion reached. A fuller account of the investigation will be published later, but in the meantime the generic name of *Nilssoniopteris* must be dropped.

We may next consider the specific name of the Yorkshire form. The Yorkshire fronds are usually somewhat narrow, about 2 cm. wide, and of considerable length. They have a narrow midrib, rather more than 1 mm. wide, with the lamina continuous above it. In casts of the upper side a sharp narrow ridge is seen, corresponding to a groove on the original leaf. The margin is entire, but the lamina is often irregularly incised into very unequal lobes (see Pl. XXIII, fig. 7). It may be undivided for a distance of 4 or 5 cm., and then show a few lobes, some of them perhaps only 5 mm. wide, above which is another undivided portion. The veins are very fine; they are given off almost at right angles to the midrib, but curve upwards more or less as they run out to the margin. They are undivided and are crowded together, three of them occurring in each millimetre. Some of the Marske specimens are well preserved in fine-grained ironstone, and show the veins very clearly; the latter appear much stouter than in the Gristhorpe specimens, but have the same frequency, and probably the stoutness is chiefly due to the mode of preservation. The Marske specimens often surpass the others in size, some of the fronds having a width of 4·5 cm.

When these fronds, which are undoubtedly of the typical *N.-tenuinervis* type, are compared with their representatives from other localities, they seem to be quite indistinguishable from Heer's species *orientalis*. They possess the same crowded fine

veins—three per millimetre, the entire or irregularly-lobed margin and the narrow midrib, together with the groove on the upper side. In some of the specimens figured by Heer the lamina is broader and the veins probably stronger than in the Gristhorpe forms, but their agreement with the Marske specimens is complete. It therefore appears to me that the name *tenuinervis* must be dropped, and that of *orientalis* substituted in its place in the lists of Yorkshire Jurassic plants.

Specimens referable to the same species have been recorded by Prof. Seward from Sutherland, and he again expresses the opinion that these are identical with examples from Yorkshire determined by Prof. Nathorst as *tenuinervis*. Among the Jurassic plants from Kamenka in Southern Russia [1] I found examples which were almost identical with the larger Marske forms, but had an undivided margin. The species has also been recorded from Korea by Yabe, from Oregon by Fontaine, from Japan by Yokoyama and Nathorst, and from Spitsbergen by the last-named writer. The species named by Heer *Nilssonia johnstrupi* is probably also very closely allied.

A specimen of this species showing some structural features has recently been described by Dr. Marie Stopes.[2]

Pseudoctenis lanei, sp. nov. (Pl. XXIV, fig. 4 & Pl. XXVI.)

Prof. Seward, in his paper on the Jurassic Flora of Sutherland, has instituted the new genus *Pseudoctenis* for fronds which have an outline similar to that seen in *Ctenis*, but usually lack the anastomosing veins of that form. He describes and figures several specimens with linear-lanceolate pinnæ, attached at a somewhat acute angle to the rachis.[3] These bear considerable resemblance to the form usually included in the genus *Zamites*, but are marked off by their obviously decurrent lower margins or pinnæ-bases. The collections here described contain several specimens which resemble the Sutherland forms, and may be referred to the genus *Pseudoctenis* (see Pl. XXIV, fig. 4). They may be described as follows:—Rachis 3 to 8 mm. broad, and marked with faint longitudinal striations. The pinnæ appear to arise laterally from it at an angle of about 45°; they may reach a length of 10 cm. and a breadth of 9 mm.; they are linear or linear-lanceolate in shape, becoming shorter and narrower towards the apex of the frond. The margins are entire, the apex acuminate, while the pinnæ taper slightly also towards the base. The lower (abaxial) margin is markedly decurrent at the base. The lamina is traversed by numerous fine parallel veins, ten of which occupy a width of about 6 mm.

The veins are not clearly seen, and there is only one indication

[1] Thomas (11) p. 86 & pl. vii, fig. 1.

[2] Stopes (10).

[3] Seward (11) p. 691 & pl. iv, figs. 67, 69; pl. vii, figs. 11, 12, 17; pl. viii, fig. 32.

of anastomosis. The pinnæ are comparatively crowded on the rachis, the centres of their bases being about 5 to 10 mm. apart. There is a specimen in the York Museum, probably of a species identical with the one just described. Prof. Seward has kindly supplied me with a photograph of it (reproduced in Pl. XXVI). It is a well-preserved smaller frond, with a rachis 2 to 3 mm. in breadth, bearing linear pinnæ 5 to 7 mm. broad and of considerable length. The bases of the pinnæ are decurrent, and numerous fine parallel veins are present which do not anastomose but occasionally fork. The specimen is labelled as coming from the Lower Shale, Scarborough, and had been identified as *Ctenis falcata*, indicating its close resemblance to the shape of that species. From the foregoing description it will be seen that these fronds are closely allied to those from Sutherland, but differ from them in possessing narrower pinnæ more obliquely placed, and bearing rather less resemblance to *Ctenis* in their form. They consequently approach very nearly to *Zamites*, and the species now under consideration was originally described by the Rev. G. J. Lane[1] as *Zamites buchianus*; they are to be distinguished from this, however, by the lateral disposition and by the decurrent bases of the pinnæ, although in the absence of a large series of specimens we cannot be absolutely certain about the latter character.

While establishing a new species for the reception of these forms, I must note that the material at present available makes it difficult for anyone to be certain as to their exact relationships to other frond-forms.

Ginkgoales.

GINKGO DIGITATA (Brongn.).

[‘Hist. Végét. Foss.’ 1828, p. 219 & pl. lxi *bis*, figs. 2–3.]

One very good specimen[2] shows a leaf which is about 7 cm. broad. The stalk is not seen; the lamina is divided nearly to the base into three or four segments, each of which is again divided half-way down. The venation is clearly seen, and shows the usual repeatedly forking character, so that in this respect, as well as in form, this specimen closely resembles the common Yorkshire type.

BAIERA LONGIFOLIA (Pomel). (Pl. XXV, figs. 3 & 4.)

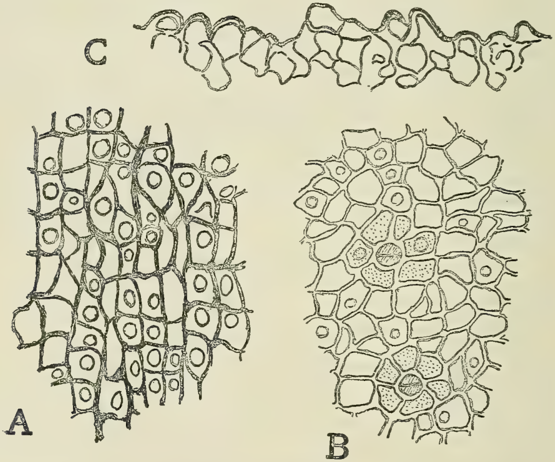
[Versamml. Gesellsch. Deutsch. Naturf. in Aachen, 1847, p. 339.]

One of the commonest fossil-plants at Marske is a *Baiera* with large leaves divided into long linear segments. I have not yet obtained an absolutely complete specimen, but one of the examples figured (Pl. XXV, fig. 3) had a length of 12 cm. measured from the region of the first dichotomy outwards, and the complete leaf must have probably exceeded 18 cm. in length. The basal portion

[1] Lane (10) p. 264 & fig.
[2] Figured in Proc. Cleveland Nat. Field-Club, vol. ii (1910) pt. 4, p. 206.

of the lamina (Pl. XXV, fig. 4) was sometimes undivided for a length of 7 cm. or more: at the lower end it is 3 mm. broad, but it widens out to 5 or 10 mm. near the place where it first divides; above this it forks four or five times, the breadth of the segments being 3 to 4 mm. The veins are not well marked, even in the best-preserved specimens; but sometimes three or four slight parallel ridges can be made out. The apices of the segments are rounded. These specimens have hitherto been denominated *Baiera gracilis*,[1] but they are really quite distinct from that species, being almost three times as large, having thicker segments,

Fig. 5.—*Camera-lucida drawings of the epidermal cells of* Baiera longifolia, *showing the characteristic papillæ and stomata on the lower side.* × *about 200.*



[A=Upper epidermis; B=Lower epidermis; C=Sectional view of the upper epidermis.]

more bifurcations, and a different cuticular structure. They approach most nearly to the specimens from Siberia described by Heer[2] as *B. longifolia* (Pomel). The only point in which the similarity is not close is in the basal portion, which is said to be much shorter in the Siberian examples; but it is doubtful whether this is a character on which great stress can be laid: they are

[1] Lane & Saunders (09) p. 82.

[2] Heer (76) p. 52 & pl. vii, figs. 2–3, pl. viii, pl. ix, figs. 1–11, pl. x, figs. 6–7.

also somewhat more divided than the examples figured by Heer.[1] The Yorkshire specimens agree fairly well with the original rather incomplete example figured by Saporta.[2]

Specimens from the grey shales have furnished good cuticular preparations, after repeated treatment with Schultz's solution (see fig. 5, p. 244). The cuticles are of the usual *Baiera* type: they are very thick, and those from the two sides of the leaf are different. One epidermis, with the thicker cuticle, was composed of cells with a more or less longitudinal arrangement but showing no traces of veins. It possessed very few stomata, and almost every cell was enlarged to form a papilla or central hump. These appear in preparations in surface-view as round spots on the cells (fig. 5 A); but their nature is seen in side view, as shown in fig. 5 C. The cuticle of the other epidermis is somewhat thinner, the cells are rounded or hexagonal, and stomata are frequent, although they do not occur abundantly. The last-named were somewhat deeply sunk, and the guard-cells are seldom clearly visible. They are surrounded by five or six subsidiary cells of a darker colour than the other epidermal cells. Their form and arrangement, which is rather characteristic of leaves of the *Ginkgo* type, is seen in fig. 5 B. The cells of the lower epidermis are also characterized by small papillate outgrowths.

Czekanowskia murrayana (Lindl. & Hutt.).

['Foss. Flor.' vol. ii (1833–35) pl. cxxi.]

This form, which is present in most of the Yorkshire plant-beds, is well represented at Marske in the sandstones and shales. The remains of the narrow leaves are usually more or less superimposed one on the other; they are ·75 to 1 mm. broad, and, although indications of forking may be occasionally made out, such are not commonly seen.

Coniferales.

Taxites zamioides (Leckenby *ex* Bean, MS.).

[Q. J. G. S. vol. xx (1864) p. 77 & pl. viii, fig. 1.]

This species, which is common in the Lower Estuarine Beds at Whitby, is represented in the collections here described by some well-preserved specimens. The slender twigs bear a number of lanceolate leaves, spirally disposed on the stem but assuming a distichous arrangement. The individual leaves have acute apices, and exhibit a marked contraction at the base, being only about 1 mm. broad at the point of insertion. They show a very distinct midrib. The leaves are rather larger than those of the usual Whitby form. One carbonized specimen of a separate leaf occurring in the grey shale has furnished excellent preparations of the cuticle. The upper side is composed of more or less uniform cells of a somewhat compressed rectangular shape, and quite devoid of stomata.

[1] See also Krasser (05) p. 606.
[2] Saporta (73) p. 464 & pl. lxvii, fig. 1.

The latter are confined to the lower side, and are arranged in two somewhat narrow rows, one on each side of the midrib. They are rather small, and were apparently sunk in the epidermis. The guard-cells have often disappeared, but are occasionally seen as two colourless cells on each side of the central slit. They are surrounded by five or six subsidiary cells, which also seem to be somewhat below the general level of the surface of the epidermis.

ELATIDES SETOSA (Phill.).

['Illustr. Geol. Yorks. pt. 1—The Yorkshire Coast' 3rd ed. (1875) p. 229.]

The specimens of *Elatides* (*Pagiophyllum*) in the collections of Mr. Lane and Mr. Saunders are rather fragmentary, but more complete examples of leafy shoots have been found at Roseberry Topping. These seem to differ somewhat from the type of *Pagiophyllum williamsoni* common at Gristhorpe. The main twigs had lateral branches given off at frequent intervals, on which small leaves were borne in the usual spiral manner. The leaves were 3 to 4 mm. long, and, when seen in side-view, are falcately curved; but in surface-view they appear bluntly pointed. They were much thinner than in *P. williamsoni*, and were flattened instead of presenting a rhomboidal section. Leaves are abundant on the younger stems, but on the older stems they are rather far apart. A female cone is seen in one specimen, lying with some twigs with which it was doubtless connected; but part of the rock is broken away, and the basal portion of the cone is not seen. The cone is about 1 cm. broad, appears to have been cylindrical, has a bluntly rounded apex, and was composed of numerous crowded scales: little can be made out concerning the details of structure of these scales. The cone, as well as the leaves, differs from that of *P. williamsoni*. In the latter it is much larger and more oval, and the apices of the scales often show a characteristic falcate form. The specimen here described might be regarded as a younger form, but in some instances depressions are seen which might well have been formed by the seeds.

The differences in both the cone and the twigs probably warrant the separation of the Marske specimens from *P. williamsoni*. They are possibly referable, however, to Phillips's species *E. (Brachyphyllum) setosa*, a type with slenderer leaves and branches. The details of structure of this form are not well known nor have any cones been discovered. The specimen figured by Phillips and the drawings given by Prof. Seward do not exhibit any very characteristic features; but, from an examination of a specimen in the Leckenby Collection, it appears to me that the Marske examples may well be included in this type. In the examples here described, however, the leaves are longer, slenderer, and more falcate than in specimens previously known; but it is doubtful whether these differences would warrant the creation of a new species for them.[1]

[1] [Many specimens of this type have recently been found at Roseberry Topping, bearing male and female cones. These seem to indicate the necessity of creating a new species, and probably a new genus for the form here described.]

V. Summary and Conclusion.

The classic researches of the last century on the Jurassic flora of Yorkshire were based on collections made from localities lying for the most part between Whitby and Filey; in the present paper the description of plants from localities on the northern side of the Cleveland Hills is commenced. The beds from which these plants have been obtained belong to the Lower Estuarine Series of the Middle Jurassic, but the flora differs considerably from that seen in the more southern localities. It differs both in its component species and in their relative abundance.

Several forms occur at Marske which have not been recorded from other localities in Yorkshire, or, in fact, from elsewhere in England. These are *Marattiopsis anglica*, *Dictyozamites hawelli*, *Pseudoctenis lanei*, and *Baiera longifolia*. The *Baiera* has been recorded from other localities in Europe and Asia, but the remainder of these species are regarded as new to science. *Stachypteris hallei* has been found at Marske, and only one other specimen is known from near Whitby.

The dominant plants at Marske are undoubtedly *Ptilophylla* (*Williamsoniæ*) of the *pecten* type. The fronds of this form are numerous, but have not yet been examined critically. Male and female *Williamsonia* flowers also occur. *Tæniopteris vittata*, too, is very abundant. *Baiera longifolia*, *Nilssonia mediana*, and *Dictyozamites hawelli* are abundant. *Sagenopteris phillipsi* is locally plentiful. The ferns do not occur so frequently: *Marattiopsis anglica* and *Coniopteris hymenophylloides* are probably the most plentiful, but the former is not so abundant as at Roseberry Topping, where it is one of the dominant plants. *Todites*, *Dictyophyllum*, and *Laccopteris* appear to be rare.

In many localities the different beds are usually characterized by different plants. Since only three beds, separated one from the other by only 10 to 15 feet, have been examined at Marske, it may be as yet unwise to compare this flora with that of the localities already known. It may be noted, however, that while the plants here described resemble those from the neighbourhood of Whitby in the abundance of fronds of *Ptilophyllum* (*Williamsonia*) *pecten* and some other types, yet the flora lacks the plentiful *Coniopteris* and *Brachyphyllum* found in the latter locality. On the other hand, *Nilssonia mediana* and *Sagenopteris phillipsi* are infrequent at Whitby, but plentiful at Gristhorpe in the Middle Estuarine Series. So far as has been noted, the flora from Roseberry Topping[1] is still more unlike that of the southern localities, although possessing close affinities to that of Marske. The detailed comparison and analysis of the floras of the various Yorkshire plant-beds will be made later, when the beds on the northern outcrop have been thoroughly examined.

Dictyozamites hawelli, one of the plants peculiar to Marske, is closely allied to *D. johnstrupi* from the Lower Jurassic, or possibly

[1] [Since this was written further investigation has emphasized this dissimilarity: see Thomas (13) p. 198.]

Rhætic, beds of Bornholm. Another new form is described in this paper, *Marattiopsis anglica*, which has affinities with *M. hœrensis* from the Lower Jurassic (Liassic ?) beds of Hör in Scania. It is possible, too, that the form described in this paper as *Wielandiella nilssoni* is allied to the Swedish *W. minor* from the Rhætic of Scania.

The suggested affinity of the Marske flora with that of the English Wealden rests on the identification of two forms represented by poorly-preserved specimens. One of these is here described as *Pseudoctenis lanei*, which was hitherto called *Zamites buchianus*. The specimen formerly described as *Nilssonia schaumburgensis* is probably a form of *N. orientalis*.

The flora is undoubtedly Middle Jurassic in type.

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VII. Notes on the Stratigraphy of the Marske Quarry. (G. J. L.)

A range of elevated ground starts from the sea-coast in the lofty cliffs of Huntcliff and Boulby, and, striking westwards, divides into two lines: the northern forming the outlying hills of Upleatham and Eston, the southern passing to the south of the great inlet in which the town of Guisborough lies, where it forms that part of the Cleveland Hills known as Guisborough Moor.

The Marske Quarry is situated on the northern face of the Upleatham Outlier, about a mile from the village of Marske-by-the-Sea. The quarry has not been worked for the last twenty years, and parts of it are inaccessible through fallen rubbish. Its altitude above sea-level is 500 feet.

The complete succession of the Lower Oolites in Yorkshire tabulated by Fox-Strangways is as follows, in descending order :—

Cornbrash.
Upper Estuarine Series.
Grey Limestone Series.
Middle Estuarine Series.
Millepore Bed.
Lower Estuarine Series, with Ellerbeck Bed.

The sequence of the beds in the Marske Quarry, from careful measurements taken of the best-exposed section, is as follows :—

	Thickness in feet	*inches.*
1. Glacial drift and clay	1	0
2. Shaly sandstones	8	4
3. Ferruginous shales	1	0
4. Shaly sandstones	2	0
5. Coaly shales	2	6
6. Shaly sandstones	6	6
7. Ferruginous bed	1	0
8. Massive, false-bedded sandstone	20	0

Beneath this lowermost bed lies the Dogger. This latter deposit, so useful for demarcation between the Lias and the Oolite in North-East Yorkshire, is not exposed in the quarry, but crops out beneath the sandstone on the flanks of the Upleatham Outlier. The geological horizon of the Marske Quarry may therefore be fixed as the Lower Oolite, and as belonging to the Lower Estuarine Series of Fox-Strangways's classification. As the Millepore Bed is absent in this locality, the Lower and Middle Estuarines may be regarded here as one continuous deposit.

Lithologically, the quarry reveals many varieties of rock, and much variation is observable throughout the quarry in the thickness of the strata exposed. The coaly, sandy, and ferruginous shales, which are all strikingly lenticular, vary in different parts of the quarry from a foot to the thinness of a sheet of notepaper. The arenaceous bed at the base of the quarry is of considerable thickness. It is also strikingly lenticular, false-bedded, and blotched with

ferruginous concretions: some of these are balls of solid iron peroxide, and others hollow boxstones showing concentric structure.

The ironstone-bed immediately above has been submitted to chemical analysis, the chief constituents and their percentages being as follows [1] :—

Total iron, Fe	42·90
Fe_2O_3	61·28
SiO_2	15·30
Al_2O_3	4·88
Water and organic matter	12·20

In this ironstone bed the plants are splendidly preserved. Plants occur, however, throughout the whole extent of the quarry where the matrix is suitable for their preservation. The coaly and sandstone shales are also richly fossiliferous. On the same slab species are often confusedly intermixed, making it difficult, if not impossible, to determine any zonal succession of forms. As the Marske beds may probably be correlated with those in other parts of North-East Yorkshire, much successful work may be done in the investigation of the Jurassic flora in the near future.

EXPLANATION OF PLATES XXIII–XXVI.

Plate XXIII.

Fig. 1. *Marattiopsis anglica*, sp. nov. Base of sterile pinna, showing rachis. (See p. 228.) Natural size.

2. *M. anglica.* Part of sterile pinna, showing venation. Natural size.

3. *M. anglica.* Part of fertile pinna, showing large synangia. Natural size.

4 *a*. *M. anglica.* Part of fertile pinna, showing smaller synangia. From the Naturhistoriska Riksmuseum, Stockholm. Natural size.

4 *b*. The same, enlarged three times to show the synangia.

5. *M. anglica.* Remains of a single synangium, which had probably dehisced before preservation. From Roseberry Topping. × 6.

6. *Todites williamsoni* Brongn. Part of sterile pinna, showing nervation. ×2·5. (See p. 228.)

7. *Nilssonia orientalis* Heer. Part of a frond with an irregularly-lobed margin. (See p. 241.) Natural size.

Plate XXIV.

Fig. 1 *a*. *Williamsonia spectabilis* Nathorst. Part of a male flower, showing sporophylls united at the base and bearing fertile segments above. (See p. 230.) Natural size.

1 *b*. *W. spectabilis.* Part of a sporophyll, showing one of the small distal lobes bearing synangia. From the counterpart of the specimen shown in fig. 1 *a*. × 2.

2. *W. spectabilis.* Specimen of a male flower in the Naturhistoriska Riksmuseum, Stockholm, showing synangia on the lobes of the sporophylls. Natural size.

3. *W. spectabilis (?)*. Impression, possibly, of a separated young sporophyll.

4. *Pseudoctenis lanei*, sp. nov. Part of a frond, showing the characteristic bases of the pinnæ. (See p. 242.) Natural size.

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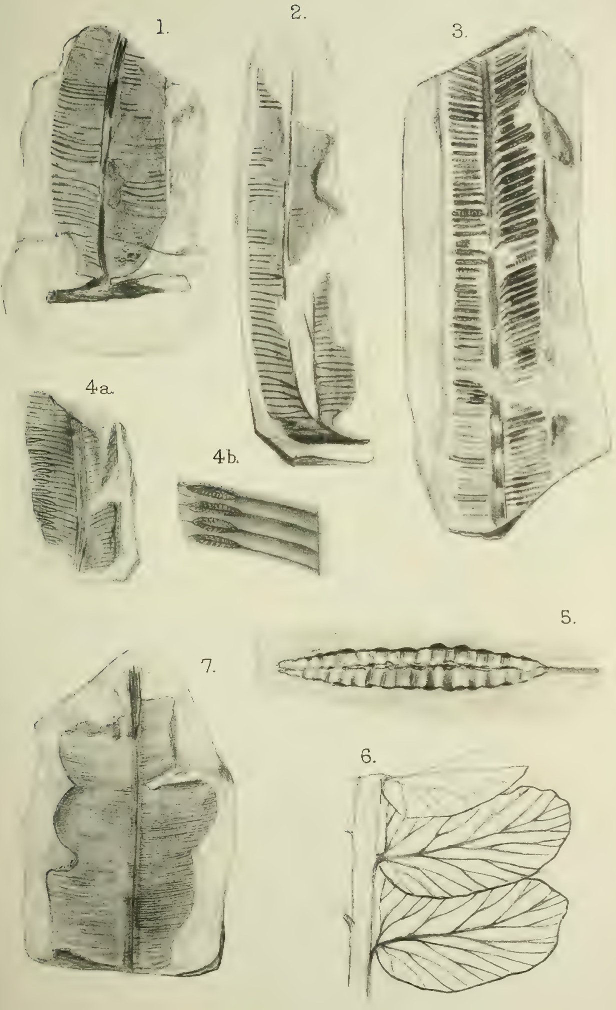
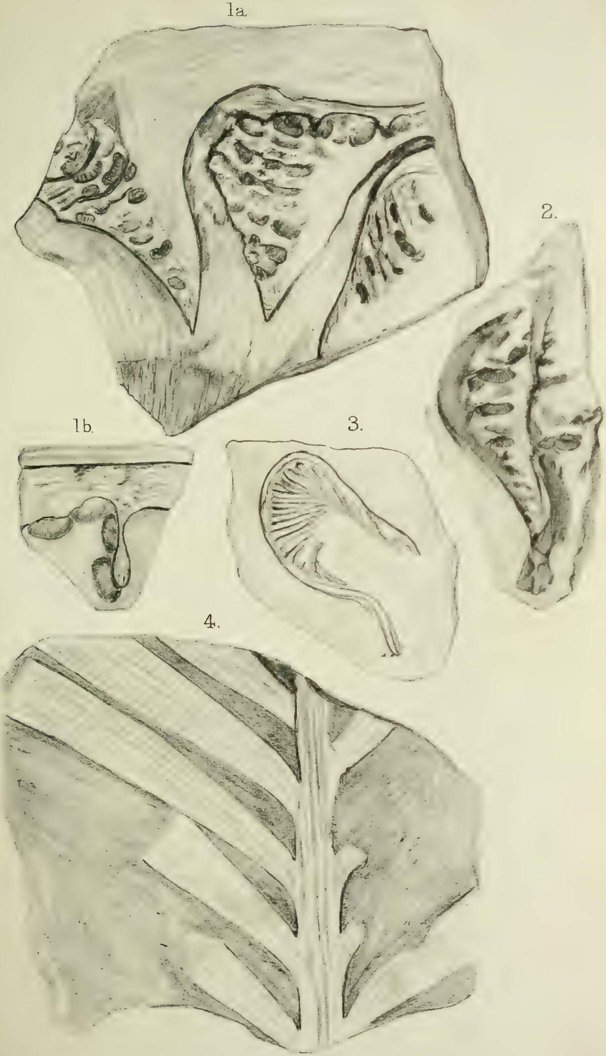
[1] Proc. Cleveland Nat. Field-Club, vol. i (1902) No. 5, p. 230.



H. Hamshaw Thomas, & Th. Ekblom, del.

Bemrose, Collo., Derby.

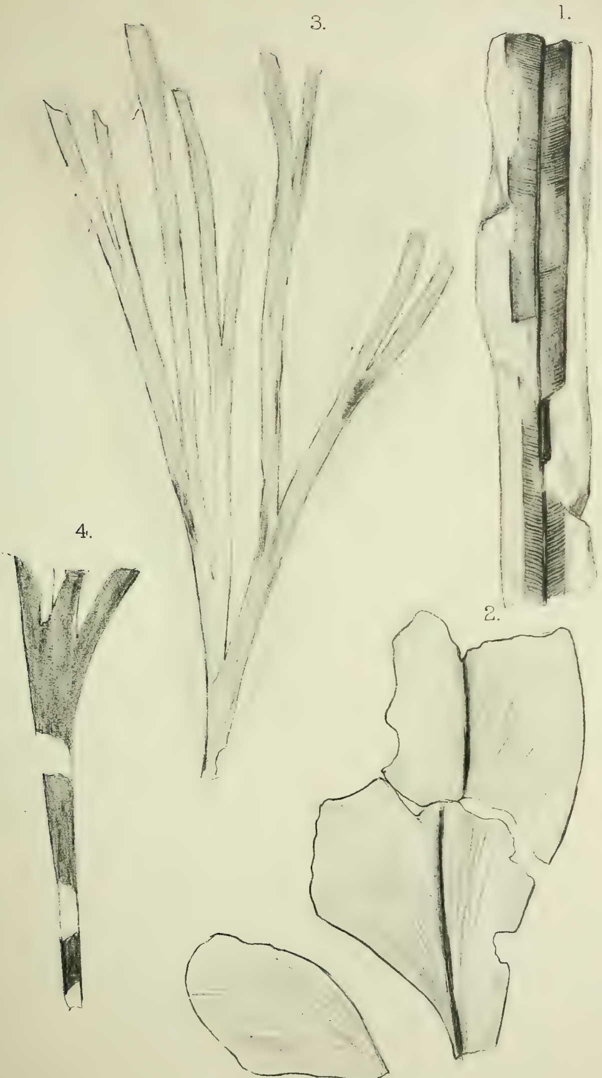
JURASSIC PLANTS FROM MARSKE.



H. Hamshaw Thomas, & Th. Ekblom, del.

Bemrose, Collo., Derby.

JURASSIC PLANTS FROM MARSKE.



H. Hamshaw Thomas, del.

Bemrose, Collo., Derby.

JURASSIC PLANTS FROM MARSKE.

Bemrose, Collo., Derby.

JURASSIC PLANTS FROM MARSKE.

PLATE XXV.

Fig. 1. *Nilssonia orientalis* Heer. Narrow form of frond with entire margin. (See p. 241.) Natural size.

2. *Sagenopteris phillipsi* var. *major*, Seward. Outline of a very large leaflet. (See p. 226.) Natural size.

3. *Baiera longifolia* Pomel. Specimen showing the large size of the leaf. (See p. 243.) Natural size.

4. *B. longifolia.* Specimen showing the long undivided basal portion of a leaf. Natural size.

PLATE XXVI.

Pseudoctenis lanei, sp. nov. Specimen in the York Museum, from near Scarborough, showing the form of the frond. See p. 243.) Natural size.

DISCUSSION.

The PRESIDENT (Dr. A. STRAHAN) remarked that the paper was based on material collected by Mr. Lane, Mr. Thomas, and others during many years of patient search, and he complimented Mr. Thomas on the good use that he had made of the collections at his disposal.

Mr. G. BARROW remarked on the special value of the plants from Marske, as their Lower Estuarine age was undoubted. The large collections made in early days were obtained mostly from Gristhorpe, and are of Middle Estuarine age. Between Whitby and Scarborough many specimens have been collected, of which the exact age is not known ; they may be either of Middle or of Lower Estuarine age.

In the northernmost outcrops of the series, the Middle Estuarine beds occur only in a portion of Eston Hill, and the speaker hoped that plants would be found here, in order to ascertain whether there are any differences between them and those from Gristhorpe ; there is a considerable difference between the strata at the two localities.

Mr. THOMAS, in replying, thanked the Fellows for the kind attention bestowed on the paper. He remarked that all the specimens described, as well as those which he had recently collected in Yorkshire, were found *in situ*, and that their exact horizon could usually be accurately determined.

14. *On the* Fossil Flora *of the* Pembrokeshire Portion *of the* South Wales Coalfield.

By Reginald H. Goode, B.A. (Communicated by E. A. Newell Arber, M.A., Sc.D., F.L.S., F.G.S. Read April 23rd, 1913.)

[Plates XXVII–XXX.]

Contents.

I. Introduction.

This paper records the results of a study of the fossil plants which I have collected from the Pembrokeshire Coalfield during the last two years; of these the best specimens are now in the Sedgwick Museum, Cambridge.

I have confined my attention principally to the excellent coast-sections between Tenby and Ragwen Point, where the coalfield is eaten into by the sea along Carmarthen Bay; and those on the eastern side of St. Bride's Bay, from Talbenny on the south to Newgale on the north. I have also collected from various colliery-'tips' between Nolton and Newgale, and have worked much of the sections where the Eastern Cleddau, the Western Cleddau, and the Daucleddau eat into the coalfield south-east of Haverfordwest. These river-sections proved, however, to be very disappointing, with the exception of that in the neighbourhood of Picton Point, and in one or two other localities.

I wish here to record my indebtedness to Dr. E. A. Newell Arber, without whose aid this work would not have been undertaken. It was at his suggestion that I first proceeded to Pembrokeshire, with the view of studying the fossil flora of this portion of the South Wales Coalfield. He has supervised the identification of the plants, particularly affording me much help in the determination of difficult species, and has given me his advice throughout, for which I return my sincere thanks.

I also gratefully acknowledge the help which I have received from various officers of H.M. Geological Survey, who have freely given me information concerning the districts surveyed by them during the last decade, and have kindly allowed me to examine

their unpublished maps and sections. In this connexion I wish to express my thanks to Dr. A. Strahan, F.R.S.; Mr. Herbert H. Thomas, M.A., B.Sc.; Mr. T. C. Cantrill, B.Sc.; Mr. E. E. L. Dixon, B.Sc.; and also to Prof. O. T. Jones, M.A., D.Sc.

II. General Geology.

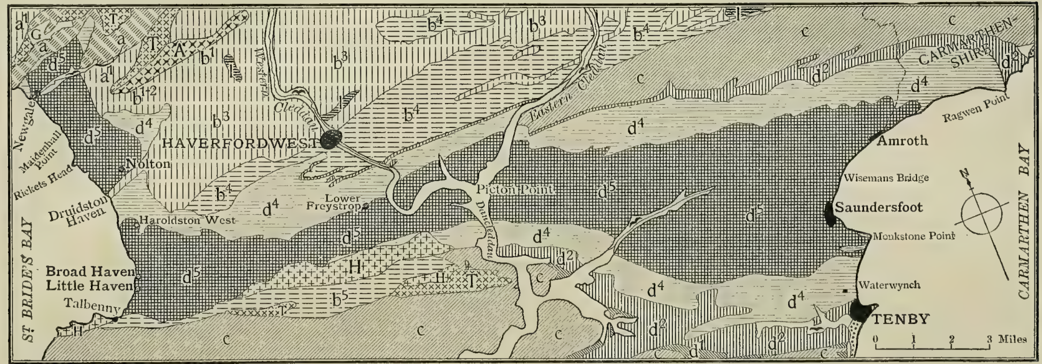
The Coal Measures of Pembrokeshire occupy a belt of country about 21 miles long, between Carmarthen Bay on the south-east, where the coalfield is disconnected with the main coalfield of South Wales, and St. Bride's Bay on the west. In the neighbourhood of Saundersfoot the outcrop is some 4 miles wide; but south of Haverfordwest it is only about a mile wide, though it broadens out again towards the coast of St. Bride's Bay. Along the northern part of the eastern side of this bay there is an area of Coal Measures situated to the north of the main Pembroke coalfield, but separated from it by a belt of 'Millstone Grit' and by a narrower belt of rock of Bala age, both of which extend to the coast. Except in the north, the strike in this area is chiefly north and south, thus contrary to the general east-and-west strike of the main mass of the coalfield.

For the greater part, the Coal Measures rest on 'Millstone Grit'; and this, between Haverfordwest and Carmarthen Bay, is followed by Carboniferous Limestone.

Roughly speaking, the eastern part of the coalfield has a synclinal form, as is indicated by the fact that the lowest measures, followed by the 'Millstone Grit' and Carboniferous Limestone, come to the surface both on the north and on the south of the coalfield. The beds, however, lie in normal superposition only on the northern side of the basin, for in the central and the southern parts the beds are complicated by inverted folds and by a large number of overthrust faults. The prevailing dip in this central and southern region is southwards, thus introducing an element of deception along this portion of coast: for, as one approaches Tenby from the north, one notes that the beds, instead of ascending in the order of sequence as the direction of the dip would suggest, in reality belong to lower and lower horizons. This apparent dipping of the Coal Measures under the 'Millstone Grit,' and of this again under the Carboniferous Limestone, is due chiefly to repeated overthrusting from the south, but also partly to inversion.

Just as in the eastern part of the coalfield, so in the central area where the coalfield is eaten into by the Eastern Cleddau, the Western Cleddau, and the Daucleddau, a synclinal form can be recognized. Here, however, it is less apparent than farther east, the beds being still more disturbed, particularly so in the southern part of this region. In this district some of the coal-seams, or 'veins' (as they are termed in Pembrokeshire), cannot be exactly correlated with those that occur farther east, for considerable changes have taken place. The 'Millstone Grit,' too, changes its character

Fig. 1.—*Geological map of the Pembrokeshire Coalfield, based on sheets 13, 14, & 17 of the quarter-inch Survey Map (1908–10).*



Cambrian
- a¹, Higher Cambrian Beds not separated from the Ordovician
- a, Solva & Caerfai Beds

Sil^n.
- b⁴, b⁵ Tarannon & Llandovery Beds

Ordov^n.
- l, Bala & Llandeilo Limestones
- b¹–b³, Bala, Llandeilo & Arenig Beds

Old Red Sandstone
- c, Conglomerates, sandstones, and marls

Carboniferous
- d⁵, Coal Measures
- d⁴, Millstone Grit
- d², Main Limestone
- d¹, Lower Limestone Shales

H, Diorite.
G, Granite.

A, Andesitic lavas.
T, Trachytic lavas,

[The dotted areas are those of blown sand, and the 'birds' wings' (⌒) indicate peat, alluvium, & river-terraces.]

as we pass westwards from the neighbourhood of the Eastern Cleddau, sandstones becoming more prominent at the expense of shales and mudstones.

In the coastal region around Little Haven, Broad Haven, etc., the beds are greatly folded and overthrust from the south, and are difficult to correlate with those farther east. The relation of the Settlings Beds and the Falling-Cliff Beds, from both of which fossil plants were obtained, one to the other and to the rest of the coalfield, will be discussed later.

It has already been mentioned that the strike of the beds in the Nolton-Newgale district (except in the north) is for the most part north and south, thus largely running parallel to the coast. The highest beds are found on the coast in the neighbourhood of Rickets Head; and, as we pass inland, we cross successively beds of lower and lower horizons. The beds of this district form a series which is quite distinct from those of other areas of the coalfield.

The shales of the coalfield are dark, sometimes markedly so, and for the most part split up into small fragments.

The earliest document that contains any material information concerning the Coal Measures of Pembrokeshire, is an essay on the 'History of Pembrokeshire'[1] left in manuscript in the year 1570 by Owen, but not published until 1796. This essay is a work of the highest interest, as it is the earliest-known example, in any language, of what can really be termed geological investigation. Between the years 1806 and 1836 mention of the coalfield was made chiefly by Martin,[2] De La Beche,[3] Forster,[4] and Murchison.[5]

In the following decade the district was surveyed by the Geological Survey, and the results were published in 1846 in a memoir by De La Beche.[6] Geological maps of Pembrokeshire on the 1-inch scale (Sheets 38 & 40) were published in connexion with this survey in 1845, the latter being revised in 1857. References to the coalfield were made by Ramsay,[7] in a memoir which was also published in 1846.

Brief mention was made, by an anonymous writer, of a portion of the coalfield in the 'Geologist'[8] for 1862; and a description of the South Wales Coalfield by Brown,[9] in which the Pembrokeshire portion is included, was published in 1874.

The chief account of the coalfield in recent years, pending the publication of the Geological Survey Memoirs, now in course of preparation, is to be found in the 'Summaries of Progress'[10] for the years 1902 to 1909. An Index-Map of Pembrokeshire

[1] Owen (1796). The numerals in parentheses refer to the Bibliography, § VII, p. 275.
[2] Martin (1806).
[3] De La Beche (1826) pp. 17–20.
[4] Forster (1831).
[5] Murchison (1836).
[6] De La Beche (1846) pp. 158–68, 221–27.
[7] Ramsay (1846).
[8] Anon. (1862).
[9] Brown (1874).
[10] Strahan (1903–10).

(quarter-inch scale, Sheet 13 & part of 17), in connexion with the recent survey, was published in 1910; and maps on the 1-inch scale (New Series, Sheets 227, 228, & 245), and on the 6-inch scale, are now being prepared for publication.

In the following table are enumerated the coal-seams that occur in the Nolton and Newgale Measures. They are arranged in the order of sequence, and are taken from the section which has been constructed for this district by Mr. H. H. Thomas, to whom I am indebted for permission to make use of it.

It has been thought, partly owing to the thickness of the Coal Measures in this region, that the higher beds may possibly be equivalent to the Pennant Grit of the main South Wales Coalfield, as was first suggested by De La Beche.[1] In that case the coal-seams that occur above those that have been definitely placed in the Lower Coal Series, as seen in the section, would be included in the Pennant Grit. In these beds the prevailing strata are sandstones with, however, some shales and mudstones. In the Lower Coal Series there are three series of sandstones: namely, between the break which is a little below the Folkeston Vein and the Quarry Vein; also on the horizon of the Brawdy Coals; and, lastly, between the lowest 'Thin Coal' and the Olive Shales which lie at the base of the Lower Coal Series. The greatest thickness of shales and mudstones occurs between the Quarry Vein and the break which is a little above the Brawdy Coals, but they also occur interspersed among the sandstones.

			Approximate distance in feet from the base of the Coal Measures.
	Rickets Head Vein		6580
	Black Cliff Vein		6360
	Cliff Vein		6050
	Hookes Vein.		
	Folly Vein		5070
Lower Coal Series.	Thin Coal.		
	Folkeston Vein.		
		Break unknown	4235
	Haggard Vein.		
	Oxland Vein		3500
	Stonepit Vein.		
	Quarry Vein.		
	Foot Vein.		
	Yard Vein	Simpson Coals.	2640
	Stink Vein		
	Five-Foot Vein		
	Three-Quarter Vein		2430
	Four Thin Coals.		
		Break unknown	1665
	Brawdy Coals.		
	Thin Coal.		
	(Farewell Rock)		

[1] De La Beche (1846) p. 159.

The following section is taken from the 'Summary of Progress' for 1905, Mem. Geol. Surv. 1906, p. 52, and shows the position of the horizons from which plants were obtained in the sequence along the Tenby and Amroth coast, and also in the central district south-east of Haverfordwest.

'GENERALIZED SECTION OF THE COAL MEASURES OF EAST PEMBROKESHIRE.

		Thickness in yards	feet	inches.
	Measures proved in the Moreton upcast shaft; details unknown ...	58	0	0
Foxholes Shaft.	Measures with three thin seams......	62	0	0
	Rock Vein of the Timber-Vein Series	0	3	0
	Measures	12	0	0
	Low Vein	0	1	8
	Measures	17	1	4
	Timber Vein	0	6	0
Ventilating Pit, Bonville's Court.	Measures	78	2	0
	Rock Vein	0	1	0
	Measures	28	1	0
	Garland Vein	0	1	3
	Measures	6	2	3
	Fiddler's Vein	0	0	6
	Measures	7	2	1
	Under Garland Vein	0	1	4
	Measures	15	0	7
Bonville's Court.	Lower Level Vein	0	1	8
	Measures	26	2	5
	Catshole Vein	0	0	8
	Measures	44	0	0
	Kilgetty Vein	0	1	6
	Measures	17	0	0
	Lady's Frolic Vein	—	—	—
	Measures	63	0	0
	Tin Pits Vein	—	—	—
	Measures	10	0	0
	Farewell Rock	—	—	—.'

III. THE FOSSIL FLORA.

So far as I am aware, there are no previous records of fossil plants from the Pembrokeshire Coalfield, with the exception that *Stigmariæ* are mentioned by De La Beche[1] as occurring in underclays in the coast-section east of Wiseman's Bridge, near Saundersfoot. In the same paper 'vertical stems of *Calamites*' are also stated to have been found at one horizon in the same section.

Since the coalfield falls naturally into three districts, the beds of which cannot be correlated exactly one with the other, it is best to consider the flora of these areas separately.

The first district to be dealt with is that which extends roughly from Nolton to Newgale, and stretches inland from St. Bride's

[1] De La Beche (1846) pp. 162–67.

Bay for about a mile and a half. This area will be considered first, because the highest beds of the coalfield are found here. The second district includes the region between Haroldston West and a little north of Talbenny. The third and largest area extends from Tenby to Ragwen Point, and stretching towards St. Bride's Bay is eaten into by the Eastern Cleddau, the Western Cleddau, and the Daucleddau.

I have succeeded in collecting from the shales associated with the Rickets Head Vein, two species, belonging to the genera *Annularia* and *Linopteris*, which are apparently new. The descriptions of these species will be found below (pp. 265-66), together with that of a species of *Lepidophyllum*, also from this vein, which has not been described before. Another species of *Linopteris* from the same coal-seam may be new also, but it seems best to refer it to *L. brongniarti* Gutb.: this plant has not, with certainty, been previously obtained from British Coal Measures.

From the Saundersfoot Measures I obtained a specimen of *Vetacapsula*, which Dr. L. Moysey thinks should be regarded as a new species. I am indebted to him for kindly supplying me with a description of it. I have omitted this species from the table in which the plants obtained from the beds of that district are set forth, since there is much doubt as to the nature of the genus *Vetacapsula*, the members probably being egg-capsules of certain fishes rather than fructifications.

(A) Nolton–Newgale District.

In the following table (p. 259) are enumerated the species which were collected from this part of the coalfield, together with their respective localities and horizons. I did not obtain any plants from the 'Millstone Grit' of this area.

(B) Haroldston West–Talbenny District.

Practically all the plants obtained from this area were collected from the Falling-Cliff Beds and the Settlings Beds. I did not obtain from the 'Millstone Grit' between Haroldston West and Druidston Haven any plants that could be identified.

The relation of the Settlings Beds to the other groups near Little Haven is not very clear, the beds along the coast being much disturbed. However, Prof. O. T. Jones, who has surveyed this district, informs me that, in his opinion, the beds below the overthrust at the Settlings are not far removed from the horizon of the group of veins worked at Broad Haven. He also believes that the sandstones of the Falling-Cliff Series are the same beds as those on the north side of the Settlings. If this be the case,

Species. (From the Nolton–Newgale District.)	(?) Pennant Grit.									Lower Coal Series.	
	Rickets Head Vein.		Sandstone.	Black Cliff Vein.	Cliff Vein.		?Cliff Vein.		Folly Vein.	Oxland Vein.	Simpson Coals.
	Rickets Head.	Near Madoc's Haven.	North Haven.	Black Cliff.	Maidenhall Point.	Nolton Colliery (tips).	Rising Sun Inn, Nolton (tips).	St. Madog's Ch., Nolton (tips).	South of Folkeston Hill (tips).	Oxland Farm (tips).	Pitt's Farm (tips).
Equisetales.											
Calamites cisti Brongn.	...	...	...	...	...	...	...	...	...	×	
Calamites schatzlarensis (?) Stur	...	...	...	...	...	...	×				
Calamites ramosus Artis	×										
Calamites sp.	...	...	×								
Calamocladus equisetiformis? (Schloth.)	×										
Palæostachya (?) sp.	×										
Annularia radiata Brongn.	×										
Annularia ingens, sp. nov.	×										
Annularia sphenophylloides (Zenk.)	×	...	...	...	...	...	...	×			
Sphenophyllales.											
Sphenophyllum cuneifolium (Sternb.)	×	...	...	...	×	?	×	...	×		
Sphenophyllum cuneifolium (Sternb.) cf. var. *saxifragæfolium* (Sternb.)	×										
Sphenophyllum majus Bronn	×	...	...	...	×						
Pteridosperms and Filicales.											
Sphenopteris obtusiloba Brongn.	×										
Sphenopteris spinosa Gœpp.	×										
Sphenopteris cf. *Sph. (Renaultia) gracilis* (Brongn.)	×										
Eremopteris artemisiæfolia (Sternb.)	...	×									
Mariopteris muricata (Schloth.)	×										
Neuropteris heterophylla Brongn.	×										
Neuropteris tenuifolia (Schloth.)	×	...	...	...	?	×	?				
Neuropteris obliqua (Brongn.)	×	...	...	...	×	×	×	...	...	×	
Neuropteris scheuchzeri Hoffm.	×	...	...	...	?	...	×	...	...	×	
Neuropteris sp.	×	...	×	...	...	...	...	×	..	...	×
Neuropteris (Cyclopteris) sp.	×										
Linopteris münsteri (Eichw.)	×										
Linopteris brongniarti [1] Gutbier	×										
Linopteris sub-brongniarti Grand'Eury	...	...	...	...	...	...	...	...	×		
Linopteris major, sp. nov.	×										
Alethopteris lonchitica (Schloth.)	...	...	...	...	...	...	...	...	×		
Alethopteris serli (Brongn.)	...	...	...	...	...	...	...	...	×		
Semina incertæ sedis.											
Cardiocarpus acutus L. & H.	...	×									
Lycopodiales.											
Lepidodendron lycopodioides Sternb.	×										
Lepidodendron sp.	×										
Lepidophyllum lanceolatum L. & H.	×	...	...	...	...	?					
Lepidophyllum minus, sp. nov.	×										
Lepidophyllum sp.	...	...	...	...	...	...	...	×	...	×	
Sigillaria lævigata Brongn.	...	...	...	...	...	...	...	×			
Sigillaria ovata Sauv.	...	...	...	...	...	...	...	×			
Sigillaria tessellata Brongn.	×										
Sigillaria sp.	×										
Stigmaria ficoides (Sternb.)	×										
Cordaitales.											
Cordaites borassifolius (Sternb.)	...	...	...	×							

[1] As mentioned above (p. 258), this plant may be a new species, although it seems best to refer it to *L. brongniarti* Gutb. Cyclopterid pinnules which may be referred to this species were also obtained (see Pl. XXVII, figs. 2 & 5).

the plants obtained from the shales at the north-eastern corner of Musclewick, which are placed above the Falling-Cliff Sandstones, might be expected to lie on about the same horizon as those obtained from the shales below the overthrust at the Settlings.

From the structure of the district it is very difficult, if not impossible, to determine the position of the beds at the Settlings, which are above the plane of overthrust, for they are faulted against all other beds. Prof. O. T. Jones, however, thinks that these beds may be higher than those below the plane of overthrust, and may therefore be the highest beds seen in the cliffs between the neighbourhood of Haroldston West and Musclewick, Little Haven.

It is difficult to correlate the Broad-Haven coals with those of any other area. Prof. Jones considers that they are almost certainly not higher than the Timber-Vein group, and may in fact be the equivalents of that group. On the other hand, they may be the representatives of some of the lower seams occurring farther east, namely, the Lower Level Vein or the Catshole Vein. Prof. Jones, however, inclines to the former view. He also informs me that all the beds along that coast are certainly not higher than the Lower Coal Series.

(*a*) Settlings Beds.

Species. (From the Haroldston West–Talbenny District.)	Cliff at the Settlings.	
	Above overthrust.	Below overthrust.
Equisetales.		
Calamites suckowi Brongn.	....	×
Calamites cisti (?) Brongn.	....	×
Calamites ramosus (?) Artis	....	×
Calamites sp.	....	×
Annularia (?) sp.	....	×
Sphenophyllales.		
Sphenophyllum cuneifolium (Sternb.)	....	×
Pteridosperms and Filicales.		
Mariopteris muricata (Schloth.)	....	×
Neuropteris tenuifolia (Schloth.)	....	×
Neuropteris obliqua (Brongn.)	×	
Neuropteris scheuchzeri Hoffm.	....	×

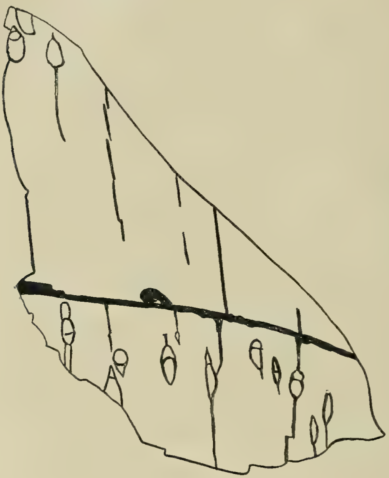
(*b*) Falling-Cliff Beds.

SPECIES. (From the Haroldston West–Talbenny District.)	Shales above the Falling-Cliff Sandstone.	Shales in the Falling-Cliff Sandstone.	Crane Vein.	? Above the Middle Vein.	80 to 100 feet below the Coal Vein.
	Cliff at Musclewick.	Falling Cliff.	Falling Cliff.	Falling Cliff.	Cliff, Strawberry Hill.
EQUISETALES.					
Calamites suckowi (?) Brongn.	...	...	...	×	
Calamites cisti (?) Brongn.	×				
Calamites ramosus (?) Artis	...	...	×		
Calamites undulatus Sternb.	...	...	×		
Calamites sp.	...	...	×	...	×
Calamocladus equisetiformis ? (Schloth.)	...	...	...	×	
Calamostachys (?) sp.	...	...	×		
Annularia galioides (L. & H.)	...	...	×		
Annularia sp.	...	...	×		
SPHENOPHYLLALES.					
Sphenophyllum cuneifolium (Sternb.)	...	×	×	×	
Sphenophyllum sp.	...	...	×		
PTERIDOSPERMS and FILICALES.					
Mariopteris muricata (Schloth.)	...	...	...	...	×
Mariopteris sp.	...	...	×		
Neuropteris heterophylla Brongn.	...	...	×		
Neuropteris tenuifolia (Schloth.)	...	...	×		
Neuropteris obliqua ? (Brongn.)	...	×			
Neuropteris sp.	...	...	×		
Odontopteris sp.	...	...	×		
Alethopteris serli ? (Brongn.)	...	...	...	...	×
Pecopteris miltoni (Artis)	...	...	...	×	
Pecopteris plumosa (Brongn.)	...	×			
LYCOPODIALES.					
Lepidodendron obovatum Sternb.	...	...	...	...	×
Lepidodendron (?) sp.	...	...	×		
Lepidophyllum lanceolatum L. & H.	...	...	...	...	×
Lepidophyllum sp.	...	...	×	...	×
Lepidostrobus sp.	...	...	×		
Stigmaria ficoides (Sternb.)	×	...	×	×	
CORDAITALES.					
Cordaites borassifolius (Sternb.)	...	×	×		
Cordaites principalis (Germar)	...	×			

The following species were also obtained from Falling Cliff, but were not found *in situ* :—*Sphenophyllostachys* sp. and *Cordaianthus pitcairniæ* (L. & H.).

Calamites undulatus Sternb. A specimen from Falling Cliff shows the external surface, or bark, with scars of adventitious

Fig. 2.—Calamites undulatus *Sternb. : external surface, showing root-scars below the node. Natural size.*



roots below the node (see fig. 2). The cast of the medullary cavity is shown on the other face, an eighth of an inch, or less, intervening.

(C) Tenby–Ragwen Point and the Cleddau District.

The flora of the Coal Measures is first enumerated, and then that of the 'Millstone Grit.'

(*a*) Coal Measures. (Lower Coal Series.)

SPECIES. (From Tenby–Ragwen Point and the Cleddau District.)	1 Timber Vein. Freystrop Colliery.	2 Below the Timber Vein. Picton Point.	3 Below the Garland Vein. Between Wiseman's Bridge & Amroth.	4 Bridge Patch (above the Fiddler's Vein). Between Wiseman's Bridge & Amroth.	5 Below the Fiddler's Vein. Between Wiseman's Bridge & Amroth.	6 Above the Lower Level Vein. Cliff, Hean Castle, Saundersfoot.	7 Kilgetty Vein. Bonville's Court Colliery.	8 Lady's Frolic Vein. Amroth, Carmarthenshire.	9 (Low down in the series.) Between Waterwynch & Monkstone Point.
EQUISETALES.									
Calamites suckowi Brongn.	...	...	...	×	×	...	...	...	?
Calamites cisti Brongn.	...	...	×	...	×				
Calamites schatzlarensis Stur	...	...	...	...	×				
Calamites ramosus Artis	...	×	...	...	...	...	...	...	×
Calamites sp.	×	...	...	...	...	...	...	...	×
Calamocladus grandis (Sternb.)	...	...	...	...	×				
Calamocladus equisetiformis (Schloth.)	...	...	...	...	×				
Palæostachya pedunculata[1] Will.	...	...	...	...	×				
Palæostachya sp.	...	...	...	...	×	×			
Annularia radiata Brongn.	...	?	...	...	×	...	...	...	×
Annularia sphenophylloides (Zenk.)	...	...	...	×					
SPHENOPHYLLALES.									
Sphenophyllum cuneifolium (Sternb.)	...	×							
Sphenophyllum sp.	×								
PTERIDOSPERMS and FILICALES.									
Sphenopteris schillingsii[2] Andræ	...	...	...	...	...	...	...	...	×
Sphenopteris cf. *sauveuri* Crép.	...	...	...	×					
Sphenopteris furcata (?) Brongn.	...	×							
Sphenopteris sp.	×								
Eremopteris (?) sp.	...	...	×						
Mariopteris muricata (Schloth.)	...	×	...	×	...	...	...	...	×
Mariopteris latifolia (Brongn.)	...	...	...	...	...	...	...	...	×
Mariopteris sp.	...	...	...	...	...	...	...	...	×
Neuropteris heterophylla Brongn.	...	×							
Neuropteris obliqua ? (Brongn.)	...	×	×	×					
Neuropteris scheuchzeri (?) Hoffm.	...	...	...	×					
Neuropteris gigantea Sternb.	?	×							
Neuropteris sp.	...	×							
Neuropteris (Cyclopteris) sp.	...	×							
Alethopteris lonchitica (Schloth.)	×	×	...	×	...	...	...	...	×
Alethopteris decurrens (Artis)	...	×							
Alethopteris serli (Brongn.)	...	×	...	...	...	...	...	...	?
Alethopteris (Spiropteris) sp.	...	×							

[1] These cones would seem best placed under the name *Palæostachya pedunculata* Will.; but they may be the cones of *Calamocladus grandis* (Sternb.), being equally as dense as, though larger than, the examples shown in Prof. Zeiller's* figures.

[2] This may be the species *Sphenopteris adiantoides* of Lindley & Hutton.

* Zeiller (1886) pl. lix, figs. 5 & 6.

(*a*) Coal Measures (*cont.*).

Species. (From Tenby–Ragwen Point and the Cleddau District.)	1 Freystrop Colliery.	2 Picton Point.	3 Between Wiseman's Bridge & Amroth.	4 Between Wiseman's Bridge & Amroth.	5 Between Wiseman's Bridge & Amroth.	6 Cliff, Hean Castle, Saundersfoot.	7 Bonville's Court Colliery.	8 Amroth, Carmarthenshire.	9 Between Waterwynch & Monkstone Point.
SEMINA INCERTÆ SEDIS.									
Cardiocarpus fluitans Dawson	...	×							
LYCOPODIALES.									
Lepidodendron obovatum Sternb.	...	...	...	...	...	...	...	...	×
Lepidodendron sp.	...	...	...	...	...	...	...	...	×
Bothrodendron sp.	...	...	...	...	...	...	...	...	×
Lepidophyllum cf. *lanceolatum* L. & H.	...	...	...	...	...	...	...	...	×
Lepidophyllum sp.	...	...	...	...	...	...	...	...	×
Lepidostrobus cf. *variabilis* L. & H.	...	...	...	...	...	...	...	...	×
Lepidostrobus sp.	...	...	...	...	...	...	...	...	×
Sigillaria tessellata Brongn.	...	...	...	...	...	...	...	...	×
Sigillaria sp.	...	...	...	...	...	...	×		
Stigmaria ficoides (Sternb.)	...	...	...	...	...	...	×	...	×
CORDAITALES.									
Cordaites borassifolius (Sternb.)	...	...	...	...	...	...	...	×	
Cordaites sp.	...	×							

(*b*) The so-called 'Millstone Grit.'

Species.	Monkstone Point.	Waterwynch.	Tenby.
EQUISETALES.			
Calamites cisti Brongn.	...	×	
Calamites ramosus Artis	?	×	
Calamites sp.	...	...	×
Calamocladus equisetiformis ? (Schloth.)	...	×	
SPHENOPHYLLALES.			
Sphenophyllum cuneifolium (Sternb.)	×		
PTERIDOSPERMS and FILICALES.			
Sphenopteris schillingsii[1] Andræ	×		
Mariopteris muricata (Schloth.)	×	×	
Mariopteris latifolia ? (Brongn.)	...	×	
Neuropteris sp.	×		
Alethopteris lonchitica (Schloth.)	...	×	
Alethopteris decurrens (Artis)	...	×	
Alethopteris sp.	×		
LYCOPODIALES.			
Lepidodendron obovatum Sternb.	×	×	
Lepidophloios acerosus (L. & H.)	×		
Lepidophyllum cf. *lanceolatum* L. & H.	×		
Lepidophyllum sp.	×		
Lepidostrobus cf. *variabilis* L. & H.	×		
Lepidostrobus sp.	×		
Stigmaria ficoides (Sternb.)	...	×	

[1] This may be the species *Sphenopteris adiantoides* of Lindley & Hutton.

Besides the species in the foregoing table, which were obtained from the 'Millstone Grit' between Tenby and Monkstone Point, the following were also collected:—*Calamites* sp. from Ragwen Point, Carmarthenshire (Basal Grit), and *Cordaites principalis?* (Germar) from Peepout Wood, Eastern Cleddau (Millstone Grit Shales).

Many specimens of branched roots were obtained from the Monkstone Point beds which might be placed in the genus *Pinnularia*, were it not for the fact that they exhibit no trace of segmentation.

(D) Descriptions of New Species.

ANNULARIA INGENS, sp. nov. (Pl. XXVIII, fig. 1.)

Horizon.—Pennant Grit (?).

Locality.—Rickets Head Vein, Rickets Head.

Diagnosis.—Stem 1 to 4 mm. wide, segmented, joints 7 to 20 mm. in length, finely striated, provided with whorls of leaves, those of successive whorls being longer than the intervening internodes. Leaves linear, acuminate, somewhat curved, 14 to 34 mm. long, 1 to 2 mm. wide in the basal half of leaf, uninerved, united at their base, numbering up to twelve in a whorl, differing slightly in length in the same whorl.

The specimen here described shows the termination of a branch bearing five whorls of leaves, which decrease rapidly in size towards the end of the branch. As the leaves are distinctly united at their bases, and the members of the same whorl differ somewhat in length, it seems justifiable to place this plant in the genus *Annularia*. It appears to me to be a new species, and I have therefore ventured to describe it under the name of *A. ingens*.

It closely approaches, however, a plant described by Renault under the name of *Asterophyllites flexuosus*.[1] It differs from this in that the leaves of the oldest whorl are larger, and taper more gradually at the apex. The stem, too, is stouter, and tapers much more rapidly. It seems that the species *A. flexuosus* should be transferred to the genus *Annularia*, especially as the leaves are described as being somewhat united at their bases.

It differs from *Annularia radiata* Brongn. in that the leaves are linear, not approaching the lanceolate type of leaf as those of that species do; and from *A. stellata* (Schloth.) in that the leaves do not become broader towards the apex, but taper gradually.

LINOPTERIS MAJOR, sp. nov. (Pl. XXVII, figs. 1 & 3.)

Horizon.—Pennant Grit (?).

Locality.—Rickets Head Vein, Rickets Head.

Only isolated pinnules of this species were found. It appears to be quite distinct from previously described species, hence I have ventured to refer to it under the name of *L. major*.

[1] Renault (1888–90) p. 417 & pl. xlviii, fig. 2.

Diagnosis.—Pinnules smooth, large, 65 to 70 mm. long, 20 to 25 mm. wide, ovate-lanceolate, margins undulating but roughly parallel for about half the length of the pinnule; the upper half of the pinnule is slightly bent and acuminate. The median nerve disappears at about half the length of the pinnule, and divides into secondary nerves. Secondary nerves numerous, fine, arising at acute angles, much arched, dividing repeatedly in their path to the margin of the pinnule and anastomosing between themselves to form a network with numerous, elongate, straight, or slightly arched meshes, which gradually become smaller towards the margin of the pinnule. The number of meshes between the median nerve and the edge of the pinnule is usually about six.

Just as *Linopteris sub-brongniarti* Grand 'Eury resembles *Neuropteris gigantea* Sternb., and *L. münsteri* (Eichw.) resembles *N. heterophylla* Brongn., so *L. major* resembles *N. scheuchzeri* Hoffm., with the exception that hairs, which are so characteristic of the latter species, are absent.

Lepidophyllum minus, sp. nov. (Pl. XXVIII, figs. 3 & 5.)

Horizon.—Pennant Grit (?).

Locality.—Rickets Head Vein, Rickets Head.

This type of sporangiophore is not a new one, but has previously been referred to as *Lepidophyllum* sp. As it seems to merit a name of its own, I have ventured to call it *L. minus.*

Diagnosis.—Lamina sagittate, the inferior angles being inflected at the base, wider at the base than the pedicel of the sporangiophore at its summit, 6 to 9 mm. long, 5 to 7 mm. wide at the base; apex acute, provided with a median nerve which is more clearly marked on the dorsal surface. Pedicel of sporangiophore cuneiform, 5 to 7 mm. long, 2 to 3 mm. wide at the summit, provided with a median nerve. In the inferior portion of the sporangiophore only the pedicel is usually present; but sometimes, also, there is an elongated area on each side of the pedicel which may be the walls of a sporangium that has become adpressed to the pedicel.

L. minus is conspicuously smaller than *L. triangulare*[1] Zeiller.

Vetacapsula minima, sp. nov. (Pl. XXX, fig. 3.)

Horizon.—Lower Coal Series.

Locality.—Bridge Patch (above the Fiddler's Vein), between Wiseman's Bridge and Amroth.

With regard to this species, Dr. L. Moysey says:—

'A very small specimen of *Vetacapsula* flattened on the surface of a piece of dark carbonaceous shale, showing a long, relatively broad pedicel, 2 mm. in

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[1] Zeiller (1886) pl. lxxvii, figs. 4–6; *id.* (1888) pp. 508–509; Arber (1910) p. 149 & pl. xvi, fig. 3.

width, curving at its broken termination. The pedicel expands gradually into a fusiform body, 5 mm. across at its broadest part, which, in a similar manner, gradually contracts into a beak that is not shown in the fossil. It is ornamented with very fine bands which run parallel to the long axis of the fossil and present no evidence of a spiral arrangement. Both the body and pedicel show to a marked degree the "central vertical suture" mentioned by Mackie [1] and again emphasized by Mr. J. W. Jackson [2] in his description of a Lancashire specimen.

'This specimen is by far the smallest that has come to hand. The fine bands or striæ are similar to those of *Vetacapsula johnsoni*,[3] but the two differ markedly in size—*V. johnsoni* measuring 20 mm. across. In size it approaches most nearly to a specimen found by Mr. Hemingway [4] in rock below the Haigh-Moor Coal at Brightside, Sheffield (now in the possession of Dr. R. Kidston); but in that specimen the bands were much broader, being about 1 mm. in width, whereas in the present specimen about four bands would be found in 1 mm.

'It might be best to consider this as *Vetacapsula* sp. indet. until more material is forthcoming; or, possibly, to give it the non-committal name of *Vetacapsula minima*.

'With regard to the "median vertical suture," it seems to occur so persistently in all the specimens that it is difficult to assume that it is due to crushing; and it is possible that it may be found subsequently that the fossil was not truly cylindrical, but that it had two, or possibly four, angles in the contour of its transverse section.'

Since the above description was written, Dr. Moysey has stated in a letter:—

'The more I think of it, the more convinced I am that it must be a new species, which might be called *Vetacapsula minima*.'

IV. Palæobotanical Evidence as to the Horizon of the Beds.

The following table (pp. 268–69) embodies first, the complete list of the species collected from the coalfield; secondly, it shows the vertical distribution of each through the so-called 'Millstone Grit,' the Lower Coal Series, and the 'Pennant Grit' of Pembrokeshire; and, thirdly, it gives a comparison of the fossil plants with those of the Upper, Transition, Middle, and Lower Coal Measures of other British coalfields, in order to show the relationship of the horizons met with in Pembrokeshire to the four recognized divisions of the Coal Measures.

The number of records from the beds of the so-called 'Millstone Grit' is naturally less than that from those of the Lower Coal Series. Since the 'Millstone Grit' contains a much smaller proportion of shales than sandstones, well-preserved plants could only be obtained from a small number of localities. Likewise, the number of records from the 'Pennant Grit' is also less than that from the Lower Coal Series, the plants being obtained from a smaller number of localities and horizons than those obtained from the Lower Coal Series.

[1] Mackie (1865–67).
[2] Jackson (1911).
[3] Moysey (1910) p. 333.
[4] *Ibid.* p. 336.

TABLE SHOWING THE VERTICAL DISTRIBUTION OF THE FOSSIL PLANTS OF THE 'PENNANT GRIT,' THE LOWER COAL SERIES, AND THE SO-CALLED 'MILLSTONE GRIT' OF THE PEMBROKESHIRE COALFIELD, AND EMBODYING A COMPARISON WITH THOSE OF THE BRITISH UPPER, TRANSITION, MIDDLE, AND LOWER COAL MEASURES.

[× = rare; ×× = moderately abundant; ××× = very abundant.]

PEMBROKESHIRE.				GREAT BRITAIN.			
Pennant Grit (?).	Lower Coal Series.	'Millstone Grit.'	SPECIES.	Upper Coal Measures.	Transition Coal Measures.	Middle Coal Measures.	Lower Coal Measures
			EQUISETALES.				
	××	...	*Calamites suckowi* Brongn.	*	*	*	*
	×	×	*Calamites cisti* Brongn.	*	*	*	*
?	×	...	*Calamites schatzlarensis* Stur	...	...	*	
×	××	××	*Calamites ramosus* Artis	*	*	*	*
	×	...	*Calamites undulatus* Sternb.	*	?	*	*
	××	...	*Calamocladus grandis* (Sternb.)	...	...	*	*
?	×	×	*Calamocladus equisetiformis* (Schloth.)	*	*	*	*
	××	...	*Palæostachya pedunculata* Will.	...	...	*	*
×	×	...	*Annularia radiata* Brongn.	*	*	*	*
×	...	...	*Annularia ingens*, sp. nov.				
××	×	...	*Annularia sphenophylloides* (Zenk.)	*	*	*	
	×	...	*Annularia galioides* (L. & H.)	...	*	*	*
			SPHENOPHYLLALES.				
×××	×××	××	*Sphenophyllum cuneifolium* (Sternb.)	...	*	*	*
×	...	...	*Sphenophyllum cuneifolium* (Sternb.) cf. var. *saxifragæfolium* (Sternb.)	...	...	*	*
×	...	...	*Sphenophyllum majus* Bronn	*	...	*	*
			PTERIDOSPERMS and FILICALES.				
×	...	...	*Sphenopteris obtusiloba* Brongn.	...	*	*	*
	×	××	*Sphenopteris schillingsii* Andræ	...	...	*	?
×	...	...	*Sphenopteris spinosa* Gœpp.	...	...	*	*
	×	...	*Sphenopteris* cf. *sauveuri* Crép.	...	...	*	
×	...	...	*Sphenopteris* cf. *Sph. (Renaultia) gracilis* (Brongn.)	...	...	*	?
	?	...	*Sphenopteris furcata* Brongn.	..	...	*	*
×	...	...	*Eremopteris artemisiæfolia* (Sternb.)	...	*	*	*
×	×××	×××	*Mariopteris muricata* (Schloth.)	*	*	*	*
	××	?	*Mariopteris latifolia* (Brongn.)	...	...	*	*
×	×	...	*Neuropteris heterophylla* Brongn.	*	*	*	*
××	×××	...	*Neuropteris tenuifolia* (Schloth.)	...	*	*	
×××	××	...	*Neuropteris obliqua* (Brongn.)	..	*	*	*
×	×	...	*Neuropteris scheuchzeri* Hoffm.	*	*	*	
	××	...	*Neuropteris gigantea* Sternb.	...	*	*	*
×××	...	...	*Linopteris münsteri* (Eichw.)	*	*	*	
×	...	...	*Linopteris brongniarti* Gutb.				
×××	...	...	*Linopteris sub-brongniarti* Grand 'Eury	...	*	*	
×	...	...	*Linopteris major*, sp. nov.				
×	×××	×××	*Alethopteris lonchitica* (Schloth.)	*	*	*	*
	××	××	*Alethopteris decurrens* (Artis)	*	*	*	*
×	××	...	*Alethopteris serli* (Brongn.)	*	*	*	
	×××	...	*Pecopteris miltoni* (Artis)	*	*	*	*
	×	...	*Pecopteris plumosa* (Brongn.)	*	...	*	*

Table showing the Vertical Distribution of the Fossil Plants (*cont.*).

Pembrokeshire.				Great Britain.			
Pennant Grit (?).	Lower Coal Series.	'Millstone Grit.'	Species.	Upper Coal Measures.	Transition Coal Measures.	Middle Coal Measures.	Lower Coal Measures.
			Semina incertæ sedis.				
×	...	...	*Cardiocarpus acutus* L. & H.	...	*	*	
	×	...	*Cardiocarpus fluitans* Dawson	*	...	*	
			Lycopodiales.				
	××	×	*Lepidodendron obovatum* Sternb.	...	...	*	*
×	...	...	*Lepidodendron lycopodioides* Sternb.	...	*	*	*
		×	*Lepidophloios acerosus* (L. & H.)	...	*	*	*
×	×	×	*Lepidophyllum lanceolatum* L. & H.	*	*	*	*
×××	...	...	*Lepidophyllum minus*, sp. nov.				
	×	×	*Lepidostrobus* cf. *variabilis* L. & H.	*	*	*	*
×	...	...	*Sigillaria lævigata* Brongn.	*	...	*	
×	...	...	*Sigillaria ovata* Sauv.	...	*	*	
×	×	...	*Sigillaria tessellata* Brongn.	*	*	*	*
××	×××	××	*Stigmaria ficoides* (Sternb.)	*	*	*	*
			Cordaitales.				
×	××	...	*Cordaites borassifolius* (Sternb.)	*	*	*	*
	×	?	*Cordaites principalis* (Germar)	...	*	*	*
	×	...	*Cordaianthus pitcairniæ* (L. & H.)	...	...	*	*

Comparing the flora of the 'Pennant Grit' with that of the Lower Coal Series, we find that all the species obtained from the former were also obtained from the latter, except:—

Annularia ingens, sp. nov.
Sphenophyllum cuneifolium cf. var. *saxifragæfolium* (Sternb.).
Sphenophyllum majus Bronn.
Sphenopteris obtusiloba Brongn.
Sphenopteris spinosa Gœpp.
Sphenopteris cf. *Sph.* *(Renaultia) gracilis* Brongn.
Eremopteris artemisiæfolia (Sternb.).
Linopteris münsteri (Eichw.).
Linopteris brongniarti Gutb.
Linopteris sub-brongniarti Grand'Eury.
Linopteris major, sp. nov.
Cardiocarpus acutus L. & H.
Lepidodendron lycopodioides Sternb.
Lepidophyllum minus, sp. nov.
Sigillaria lævigata Brongn.
Sigillaria ovata Sauv.

Of these all are rare in the 'Pennant Grit,' being represented by only a very few specimens, with the exception of the following, which are abundant:—

Linopteris münsteri (Eichw.).
Linopteris sub-brongniarti Grand'Eury.
Lepidophyllum minus, sp. nov.

The commonest species on this horizon are:—

Sphenophyllum cuneifolium (Sternb.).
Neuropteris obliqua (Brongn.).
Linopteris münsteri (Eichw.).
Linopteris sub-brongniarti Grand'Eury.
Lepidophyllum minus, sp. nov.

Of these, *Sphenophyllum cuneifolium* (Sternb.) is also very abundant, and *Neuropteris obliqua* (Brongn.) is not so common, in the Lower Coal Series, while the other three species have not been recorded from these beds. The commonest plants at this latter horizon are:—

Sphenophyllum cuneifolium (Sternb.).	*Alethopteris lonchitica* (Schloth.).
Mariopteris muricata (Schloth.).	*Pecopteris miltoni* (Artis).
Neuropteris tenuifolia (Schloth.).	*Stigmaria ficoides* (Sternb.).

Turning to the so-called 'Millstone Grit,' we find only one species that has not been obtained from the higher beds, all the other species having been found in the Lower Coal Series. This species is *Lepidophloios acerosus* (L. & H.). In these beds the commonest species are *Mariopteris muricata* (Schloth.) and *Alethopteris lonchitica* (Schloth.).

(1) Pennant Grit (?).

Comparing the fossil flora of the 'Pennant Grit' with that of the Upper, Transition, Middle, and Lower Coal Measures elsewhere in Britain; leaving out of consideration the two doubtful and the three new species, and also *Linopteris brongniarti* Gutb. which has not with certainty been previously obtained from British Coal Measures, we find that out of the twenty-seven species recorded, fifteen occur in the Upper Coal Measures, none of which are characteristic of that horizon; twenty-two in the Transition Coal Measures; all occur in the Middle Coal Measures, three: namely, *Sphenophyllum cuneifolium* var. *saxifragæfolium* (Sternb.), *Sphenopteris spinosa* Gœpp., and *Sph. (Renaultia) gracilis* (Brongn.), not occurring above and nine not below that horizon; while seventeen are found in, and one, namely, *Sph. (Renaultia) gracilis* (Brongn.), is doubtfully recorded from, the Lower Coal Measures, nine of these being common to all the divisions of the Coal Measures.

These beds cannot, therefore, be regarded as belonging to the Pennant Grit, for the fossil flora distinctly indicates a Middle, and not a Transition,[1] Coal-Measure horizon, there being no admixture of species characteristic of the Upper and of the Middle Coal Measures. In other words, no plants occur which are not found at a lower horizon than the Transition Series, though some are present which do not extend higher than these beds or even the Middle Coal Measures.

(2) Lower Coal Series.

Turning now to the Lower Coal Series, we find, leaving out one doubtful species, that out of the thirty-five species recorded, twenty-one occur in the Upper Coal Measures, none of these, however,

[1] Kidston (1894) p. 574.

being characteristic of that horizon; twenty-four occur in, and one, namely, *Calamites undulatus* Sternb., is a doubtful determination from, the Transition Coal Measures; all occur in the Middle Coal Measures, of which two: namely, *Calamites schatzlarensis* Stur and *Sphenopteris sauveuri* Crép., are characteristic of, and seven do not occur below, that horizon; while twenty-seven are found in the Lower Coal Measures, fifteen of these being common to all the divisions of the Coal Measures.

Since all the species obtained from the Lower Coal Series occur in, and some are not found below, and others not above, the Middle Coal Measures, this must be regarded as a typical Middle Coal-Measure horizon.

Settlings Beds.

From the Settlings Beds I obtained *Neuropteris tenuifolia* (Schloth.), which I did not find in the Lower Coal Series farther east, either along the Saundersfoot coast or in the central area south-east of Haverfordwest. I also obtained *Neuropteris obliqua* (Brongn.) and *N. scheuchzeri* Hoffm., which were doubtfully recorded from the eastern districts.

The flora of these beds, and especially the occurrence of *N. scheuchzeri* Hoffm., seems to indicate that they belong to a fairly high Middle Coal-Measure horizon, probably higher than the beds of the Lower Coal Series exposed along the Saundersfoot coast; they may even belong to a higher horizon than the Timber Vein group.

Falling-Cliff Beds.

From the Falling-Cliff Beds I obtained the following species which are not recorded from the Lower Coal Series of the eastern areas:—

Calamites undulatus Sternb.	*Odontopteris* sp.
Calamostachys (?) sp.	*Pecopteris miltoni* (Artis).
Annularia galioides (L. & H.).	*Pecopteris plumosa* (Brongn.).
Sphenophyllostachys sp.	*Cordaianthus pitcairniæ* (L. & H.).
Neuropteris tenuifolia (Schloth.).	

Besides these, *Neuropteris obliqua?* (Brongn.) and *Lepidophyllum lanceolatum* L. & H. were obtained, which are doubtfully recorded from the Lower Coal Series of the eastern districts, and also *Cordaites principalis* (Germar), which was a somewhat uncertain determination from the 'Millstone Grit' of the Eastern Cleddau.

This flora does not seem to supply any definite indication that these beds belong to a higher horizon than those which occur farther east. If, however, these beds lie immediately below the Settlings Beds (as has been suggested by Prof. O. T. Jones), and if we rely on the evidence which the flora of these latter beds affords, it seems possible that the Falling-Cliff Beds may also belong to a higher horizon than those which occur farther east.

(3) The so-called 'Millstone Grit.'

The fossil plants obtained from the so-called 'Millstone Grit' were nearly all collected from the beds between Monkstone Point and a little south of Waterwynch on the Tenby coast.

In these beds, leaving out of account two doubtful determinations, we find that all of the thirteen species recorded occur in the Middle and Lower Coal Measures. Four, namely, *Sphenophyllum cuneifolium* (Sternb.), *Sphenopteris schillingsii* Andræ, *Lepidodendron obovatum* Sternb., and *Lepidophloios acerosus* (L. & H.) are unknown from the Upper Coal Measures, and two, *Sphenopteris schillingsii* Andræ and *Lepidodendron obovatum* Sternb., are unknown from the Transition Series. Thus the horizon is clearly either Middle or Lower Coal Measures. The occurrence of *Sphenopteris schillingsii* Andræ and *Lepidophloios acerosus* (L. & H.) in the Monkstone Point beds, both of which are very rare in the Lower Coal Measures, makes it more probable that at least these beds belong to the Middle division rather than to the Lower, though the proof offered is not conclusive.

Further, the flora of these Monkstone Point and Waterwynch beds is very similar to that of the beds in the intervening ground which have been placed low down in the Lower Coal Series. These latter beds undoubtedly belong to the Middle Coal Measures, especially as specimens which may be compared with *Alethopteris serli* (Brongn.) have been obtained from them. There is, also, no apparent unconformity between these Middle Coal Measures and the so-called 'Millstone Grit' of Monkstone Point, or between the former and those seen in the cliff between 480 and 780 yards south-west of Monkstone Point. Hence it may be inferred that these 'Millstone Grit' beds and those of the neighbouring Lower Coal Series are on almost the same horizon. It seems, therefore, that at least these particular 'Millstone Grit' beds belong to the Middle Coal Measures, those near Waterwynch being here excluded, as they are separated by overthrust faults from the Coal Measures.

V. The Fossil Flora of the Pembrokeshire Coalfield compared with that of the Main Portion of the South Wales Coalfield.

The only extant account of the fossil flora of the South Wales Coalfield is that by Dr. Kidston[1] which was published in 1894. Our knowledge of the fossil flora of this coalfield is still, however, very imperfect, and much remains to be done.

(a) The Fossil Floras of the 'Pennant Grit' of Pembrokeshire and the Lower Pennant, or Pennant Grit, of South Wales.

The fossil flora of the 'Pennant Grit' of Pembrokeshire is, as we have seen, a Middle Coal-Measure flora; while that of the

[1] Kidston (1894).

Lower Pennant of the main portion of the South Wales Coalfield has been shown by Dr. Kidston to be a true Transition Coal-Measure flora. A comparison of the two floras, however, shows that all the species occurring in the Lower Pennant which are Upper Coal-Measure forms, are absent from the 'Pennant Grit' of Pembrokeshire, thus confirming the conclusions which were arrived at above. These Upper Coal-Measure plants are:—

Annularia stellata (Schloth.).
Sphenophyllum emarginatum Brongn.
Sphenopteris neuropteroides (Boulay).
Neuropteris flexuosa Brongn.
Neuropteris macrophylla Brongn.
Neuropteris ovata Hoffm.[1]
Odontopteris lindleyana Sternb.
Lepidodendron dichotomum Zeiller.
Cordaites angulostriatus Grand'Eury.

These have not been obtained from Pembrokeshire.

There are also at least nineteen species which have been recorded from the Lower Pennant of the main portion of the South Wales Coalfield, but have not been obtained from the 'Pennant Grit' of Pembrokeshire.

There are, in fact, only nine[2] species known in common to the two series. *Calamocladus equisetiformis* (Schloth.) is recorded from the Lower Pennant of South Wales, but is only a doubtful determination from the 'Pennant Grit' of Pembrokeshire.

Further, there are twenty-one or twenty-two Pembrokeshire species which are unknown from the Lower Pennant of the main portion of the South Wales Coalfield.

It is obvious, therefore, that there is a considerable difference between the fossil floras of the 'Pennant Grit' of Pembrokeshire and the Lower Pennant of the main part of the South Wales Coalfield, even though most of the species which are recorded from the latter are plants which occur in the Middle Coal Measures.

(*b*) The Fossil Floras of the Lower Coal Series, including that of the 'Pennant Grit,' of Pembrokeshire and the White Ash Series of South Wales.

The fossil plants of the Lower Coal Series of Pembrokeshire, including those of the 'Pennant Grit,' can be more exactly compared with those recorded from the White Ash Series, or Lower Coal Series, of the main portion of the South Wales Coalfield: for all belong to the Middle Coal-Measure horizon.

There are, however, at least twenty-five species which have been recorded from the White Ash Series, but have not been obtained from the Lower Coal Series, or the 'Pennant Grit,' of Pembrokeshire.

Twenty species are common to the Lower Coal Series, including the 'Pennant Grit,' of Pembrokeshire, and the White Ash Series.

[1] Recorded by Mr. E. E. L. Dixon. See Strahan (1907) p. 156.

[2] Two of these have been recorded from the Pennant Series of the main part of the South Wales Coalfield by Mr. E. E. L. Dixon. See Strahan (1907) p. 156.

Further, the following nineteen species have been obtained from the Lower Coal Series of Pembrokeshire, but have not been recorded from the White Ash Series; they are, therefore, additions to our knowledge of the Middle Coal Measures of South Wales:—

Calamites cisti Brongn.
Calamites schatzlarensis Stur.
Calamocladus grandis (Sternb.).
Palæostachya pedunculata Will.
Annularia radiata Brongn.
Annularia sphenophylloides (Zenk.).
Annularia galioides (L. & H.).
Sphenopteris schillingsii Andræ.
Sphenopteris cf. *sauveuri* Crép.
Sphenopteris furcata (?) Brongn.
Mariopteris latifolia (Brongn.).
Neuropteris obliqua (Brongn.).
Neuropteris scheuchzeri Hoffm.
Alethopteris serli (Brongn.).
Pecopteris plumosa (Brongn.).
Cardiocarpus fluitans Dawson.
Lepidostrobus cf. *variabilis* L. & H.
Cordaites borassifolius (Sternb.).
Cordaianthus pitcairniæ (L. & H.).

Furthermore, from the 'Pennant Grit' of Pembrokeshire, which, as we have seen above, may be regarded as belonging to the Middle Coal-Measure horizon, the following thirteen species have been obtained. These species have not been recorded from the Lower Coal Series, either of Pembrokeshire or of the main portion of the South Wales Coalfield, and may therefore be regarded as additional records to those mentioned above for the Middle Coal Measures of South Wales:—

Annularia ingens, sp. nov.
Sphenophyllum cuneifolium cf. var. *saxifragæfolium* (Sternb.).
Sphenophyllum majus Bronn.
Sphenopteris spinosa Gœpp.
Sphenopteris cf. *Sph. (Renaultia) gracilis* Brongn.
Linopteris münsteri (Eichw.).
Linopteris brongniarti Gutb.
Linopteris sub-brongniarti Grand'Eury.
Linopteris major, sp. nov.
Cardiocarpus acutus L. & H.
Lepidodendron lycopodioides Sternb.
Lepidophyllum minus, sp. nov.
Sigillaria ovata Sauv.

It will be seen that, although both the Lower Coal Series of Pembrokeshire, including the 'Pennant Grit,' and the White Ash Series of the main portion of the South Wales Coalfield are Middle Coal Measures, there is considerable difference in the occurrence of the species. There are, however, more species common to these beds than to the 'Pennant Grit' of Pembrokeshire, by itself, and the Lower Pennant of the main part of the South Wales Coalfield.

It is not possible to compare the fossil flora of the so-called 'Millstone Grit' of Pembrokeshire with that of these beds in the main portion of the South Wales Coalfield, for there are no records from the latter beds.

VI. Conclusions.

Of the fifty-three species here recorded from the Pembrokeshire Coalfield, three are new species, and one, *Linopteris brongniarti* Gutb., has not with certainty been found before in Britain.

From the palæobotanical evidence it has been shown that the 'Pennant Grit' of Pembrokeshire cannot be regarded as the equivalent of the Pennant Grit of the main portion of the South Wales Coalfield: for the plants indicate that these beds are Middle

Coal Measures, and do not belong to the Transition Series. The Lower Coal Series of Pembrokeshire has also been proved to belong to the Middle Coal Measures; while the Settlings Beds, and perhaps the Falling-Cliff Beds as well, have also been shown to lie probably at a higher horizon than the Lower Coal Series as developed farther east along the Saundersfoot coast, and possibly higher than the Timber Vein Group.

Until more plants have been obtained from the so-called 'Millstone Grit' of Pembrokeshire, it is impossible to fix definitely the horizon of this group from the palæobotanical evidence. However, the so-called 'Millstone Grit' beds of Monkstone Point have been shown to belong probably to the Middle Coal Measures.

It has also been shown that there are considerable differences in the occurrence of the species in the Pembrokeshire Coalfield, when they are compared with those which have been recorded from the main portion of the South Wales Coalfield. In this connexion it has been indicated that thirty-two species have been added to our lists of the flora of the Middle Coal Measures of South Wales.

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EXPLANATION OF PLATES XXVII-XXX.

[All the specimens figured are in the Sedgwick Museum, Cambridge. The photographs were taken by Mr. W. Tams, of Cambridge.]

Plate XXVII.

Fig. 1. *Linopteris major*, sp. nov. Portion of a pinnule, from the Rickets Head Vein, Rickets Head. Natural size. (See pp. 265–66.)

2. *Linopteris (Cyclopteris) brongniarti* Gutb. Portion of a pinnule, from the Rickets Head Vein, Rickets Head. × $\frac{3}{2}$. (See pp. 258 & 259.)
3. *Linopteris major*, sp. nov. Portion of a pinnule, from the Rickets Head Vein, Rickets Head. Very slightly reduced.
4. *Linopteris sub-brongniarti* Grand'Eury. Pinnules, from Folly Vein 'tips' near Folkeston Hill, Nolton. × $\frac{3}{2}$.
5. *Linopteris brongniarti* Gutb. A pinnule, from the Rickets Head Vein, Rickets Head. × 2.

Plate XXVIII.

Fig. 1. *Annularia ingens*, sp. nov. Termination of a branch with whorled leaves, from the Rickets Head Vein, Rickets Head. Very slightly enlarged. (See p. 265.)

2. *Alethopteris serli* (Brongn.). Rachis with pinnules, from Folly Vein 'tips' near Folkeston Hill, Nolton. Natural size.
3. *Lepidophyllum minus*, sp. nov. Portion of a sporangiophore, from the Rickets Head Vein, Rickets Head. × $\frac{3}{2}$. (See p. 266.)
4. *Sigillaria tessellata* Brongn. Part of stem with leaf-scars, from the Rickets Head Vein, Rickets Head. Very slightly reduced.
5. *Lepidophyllum minus*, sp. nov. A sporangiophore, from the Rickets Head Vein, Rickets Head. × $\frac{3}{2}$.
6. *Cardiocarpus acutus* L. & H. Seed, from the Rickets Head Vein, near Madoc's Haven. × $\frac{3}{2}$.

Plate XXIX.

Fig. 1. *Palæostachya pedunculata* Will. Fertile shoot, bearing cones, from below the Fiddler's Vein, between Wiseman's Bridge and Amroth. Natural size. (See p. 263.)

2. *Sphenophyllostachys* sp. A cone, from Falling Cliff, Little Haven. × 3.
3. *Palæostachya pedunculata* Will. Portions of cones, from below the Fiddler's Vein, between Wiseman's Bridge and Amroth. Natural size. (See p. 263.)
4. *Palæostachya* sp. Portions of cones, from below the Fiddler's Vein, between Wiseman's Bridge and Amroth. Very slightly reduced.
5. *Cordaianthus pitcairniæ* (L. & H.). Portion of cone, from Falling Cliff, Little Haven. Very slightly enlarged.

Plate XXX.

Fig. 1. *Calamocladus grandis* (Sternb.). Portion of a leafy, branched shoot, from below the Fiddler's Vein, between Wiseman's Bridge and Amroth. Slightly reduced.

2. *Sphenopteris schillingsii* Andræ. A branched stem bearing pinnules, from the 'Millstone Grit,' Monkstone Point. Natural size. (See p. 264.)
3. *Vetacapsula minima*, sp. nov. From the Bridge Patch (above the Fiddler's Vein), between Wiseman's Bridge and Amroth. × $\frac{3}{2}$. (See pp. 266–67.)

Discussion.

Dr. Arber desired to congratulate the Author on the very considerable additions which he had made to our knowledge of the fossil flora of South Wales. The new species described by the Author were of interest, especially those referred to the genus *Linopteris*. As the speaker had pointed out some years ago, the species of this genus mimic in habit those of *Neuropteris* in an extraordinary degree. Among the new species of *Linopteris* described by the Author appears to be the long-expected homœomorph of *Neuropteris scheuchzeri* Hoffm.

The fact that all the plants described by the Author indicated a Middle Coal-Measure horizon was certainly a remarkable conclusion; but the speaker felt less surprised at this result, now that the horizon of the beds in the Forest-of-Dean Coalfield on the eastern side of the great South Wales Coalfield was known. So far, it would appear safer to assume that the Pembrokeshire, South Wales, and Forest-of-Dean coalfields were unrelated areas, except tectonically.

The point raised by the Author with regard to the possible absence of true Millstone Grits in Pembrokeshire was certainly in keeping with recent conclusions as to the absence of this horizon in the West-of-England coalfields; but, as the Author doubtless admitted, further proof of this contention must be forthcoming before the matter could be regarded as settled.

Prof. O. T. Jones associated himself with the previous speaker in congratulating the Author on a valuable and interesting piece of research, carried out in a region of great difficulty. While not desiring to criticize the Author's work, the speaker wished to point to some of the possible consequences of the investigation. It was suggested that the Millstone Grit yielded plants of Middle Coal-Measure age. In many parts of Pembrokeshire it was clear that there was an unconformity at the base of the Millstone Grit, so that it was conceivable that higher portions of the Upper Carboniferous might thereby rest upon Carboniferous Limestone. Against this supposition there were several facts:—(1) In other parts of Pembrokeshire there was a close connexion between the higher beds of the Limestone and the basal members of the Millstone Grit, thus rendering it improbable that a physical break existed there; (2) The Millstone Grit of Pembrokeshire was exceedingly similar in its succession of lithological characters to that of the northern outcrop of the coalfield farther east (Carmarthenshire and Glamorgan), where strict conformity prevails, and a perfectly gradual transition occurs between the two formations.

Either, therefore, the Millstone Grit of Carmarthenshire and Pembrokeshire are of the same Middle Coal-Measure age, and the representatives of the underlying Lower Coal Measures must be looked for among the Carboniferous Limestone Series; or they are of different ages, in which case the two similar formations would be homotaxial but not contemporaneous: or, again, the

apparent conformity between the formations is illusory, and conceals a great break in the physical history of these regions.

Further, various parts of the Millstone Grit of South Wales have yielded marine fossils which have been claimed as Pendleside species. If this determination is correct, it is hardly compatible with the Middle Coal-Measure age suggested by the Author.

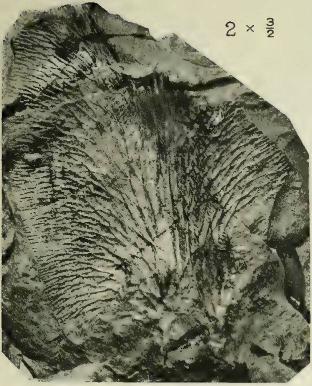
These possibilities should be borne in mind before undue weight is attached to the palæobotanical evidence, especially when this appears to contradict the stratigraphical evidence, as also the palæontological evidence derived from a study of other groups of fossils.

Mr. E. E. L. DIXON commented on the lack of evidence of Lower Coal Measures in South Wales, mentioned by the previous speaker. In Pembrokeshire a continuous sequence from Carboniferous Limestone into Coal Measures was, unfortunately, nowhere observable along the south side of the coal-basin, where greater freedom from unconformities might be expected than along the north side. However, there was no doubt that the coast-section north of Tenby included part of the Pendleside Series, and that a considerable thickness of strata intervened between the latter and the lowest of the beds that had yielded a Middle Coal-Measure flora. The rocks were chiefly marine, and had yielded few plants; again, they were interrupted by several disturbances of unknown magnitude. Hence it would be premature, in the present state of our knowledge, to say that a representative of the Lower Coal Measures does not exist on the south side of the Pembrokeshire Coalfield. South of the main part of the South Wales Coalfield, a representative might possibly be found north of the Carboniferous Limestone of the Gower peninsula; for there the Pendleside Series, with *Glyphioceras spirale*, was in evidence and, doubtless, passed up into the Coal Measures through an intermediate series of shales with sandstones. Unfortunately, there was no continuous coast-section.

Dr. T. F. SIBLY spoke of the difficulties which were being revealed in increasing degree by progress in the zonal investigation of the Lower and Upper Carboniferous rocks. Palæontological studies had shown that the marine Lower Carboniferous extended to higher horizons in the Midland regions than in South Wales; while palæobotanical evidence indicated that the Upper Carboniferous of the Midlands included lower horizons than had been detected in the Upper Carboniferous of South Wales. He suggested that the solution of the problem might ultimately be found in the existence of at least one widespread unconformity or break within the Carboniferous succession of South Wales and the adjoining regions.

With reference to the question of the age of the Millstone Grit, mentioned by a previous speaker, he drew attention to the fact that the 'Pennant Grit' transgressed persistently from lower to higher floral horizons in passing eastwards from Pembrokeshire to Monmouthshire and the Forest of Dean; and he suggested that an explanation involving similar transgression, but upwards from east

$2 \times \frac{3}{2}$

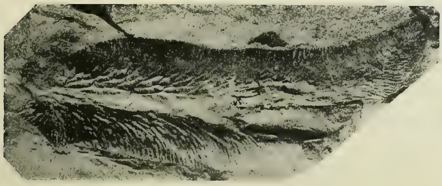


1.

$4 \times \frac{3}{2}$

3.

$5 \times \frac{2}{1}$



W. Tams, Photo.

Bemrose, Collo., Derby.

PEMBROKESHIRE COAL-MEASURE PLANTS.

2.

1.

$5 \times \frac{9}{2}$

4.

$3 \times \frac{9}{2}$

$6 \times \frac{9}{2}$

W. Tams, Photo.

Bemrose, Collo., Derby.

PEMBROKESHIRE COAL-MEASURE PLANTS.

3.

$2 \times \frac{3}{1}$

1.

4.

5.

W. Tams, Photo.

Bemrose, Collo., Derby.

PEMBROKESHIRE COAL-MEASURE PLANTS.

1.

$3 \times \frac{7}{2}$

2.

W. Tams, Photo.

Bemrose, Collo., Derby.

PEMBROKESHIRE COAL-MEASURE PLANTS.

to west, might be applicable to a portion at least of the Millstone Grit of South Wales.

Prof. HULL pointed out that the dissimilarity between the South Wales Coalfield and those of the Midlands was amply to be accounted for on the grounds that these coal-areas were never connected, but were separated one from the other by a ridge of pre-Carboniferous rocks, extending from North Wales and Shropshire into the centre and east of England under the Mesozoic formations. With regard to the Lower Coal Measures of South Wales, they differed from the succeeding Middle and Upper divisions, as they contained numerous species of marine shells, such as *Productus*, *Orthis*, *Nautilus*, etc. These marine, though shallow-water, deposits were succeeded by deposits of freshwater origin.

The AUTHOR, in reply, thanked the Fellows present for their kind reception of the paper. He pointed out that he only obtained fossil plants from some of the highest beds of the so-called 'Millstone Grit': namely, from those at, and in the neighbourhood of, Monkstone Point; with the principal exception of some from beds immediately south of Waterwynch, which, however, give no definite indication of the horizon of the beds in that district. He thought that the evidence as to the horizon of the Monkstone-Point beds would be seen more clearly when the paper was published.

15. *The* Loch Awe Syncline (Argyllshire).

By Edward Battersby Bailey, B.A., F.G.S. (Read February 26th, 1913.)

[Plates XXXI & XXXII.]

Contents.

I. Introduction.

The district described in the present paper forms portion of the low coastal region of Argyllshire, and presents few physical difficulties to the investigator. There are, however, other difficulties, resulting from the fact that igneous and sedimentary schists occur together here in about equal proportions, and have been alike subjected to a system of small-scale isoclinal folding; moreover, though lavas are well represented, fully half the igneous schists are sills, and so are of little use for stratigraphical purposes.

Under the circumstances, it is not surprising that progress has been slow. Macculloch, writing in 1819 [1, p. 292],[1] did himself less than justice, for he seems to have decided against the igneous origin of any of the schists of the region, erecting his Chloritic Formation to include the whole assemblage. In regard to structural matters he was more fortunate, for he gave a clear account of the lie of the rocks in the southern part of the district, where he located

> 'a line of vertical beds . . . towards which the strata converge on each side, both from the south-eastern and north-western boundaries'

[1, pp. 288–89]. In nature, of course, the line is rather vague, being more correctly designated as a narrow belt, where both bedding and cleavage are often extremely steep or vertical. This belt runs from the eastern shores of Loch Sween, north-north-eastwards through the southern end of Loch Awe. For some miles to the south-east of its course the prevalent dip of both bedding and cleavage is towards the north-west, and *vice versâ*. There is also a tendency for the angles of inclination to be higher near the central belt than at a distance; but this does not preclude the existence of many open anticlines and synclines, affecting bedding, not cleavage, quite close up to the central line.

[1] The numerals in brackets refer to the Bibliography, § VI, p. 298.

There followed a long interval during which very little was done; but at last, in a paper read in 1860, the late Mr. Jamieson [2] demonstrated the truly igneous nature of many of the schists. As a matter of fact, their porphyritic and other igneous structures are frequently preserved in great perfection; in other instances, however, careful comparison and examination are necessary before a confident opinion as to their nature can be entertained. Mr. Jamieson called all these igneous rocks 'greenstones'; but the term 'epidiorite' has been so commonly applied to them since, that it will be used in the sequel. He gave an excellent account of the various sedimentary schists which accompany the epidiorites. He also advanced the view that the structure of the district is synclinal; but, when we look into the matter, we find that he had nothing to go upon save the inward inclination of the strata, and this, considering that isoclinal folding is prevalent, is not in itself a sufficient criterion.

In 1885 Mr. J. B. Hill began mapping the district for the Geological Survey, and by degrees brought order out of chaos. Half of the area included in the appended map (Pl. XXXII) has been surveyed by him, and the results obtained have been fully set forth in the maps and memoirs of the Survey and in papers communicated to this Society. We may notice especially a paper [7] published in 1899, which incidentally presents his position in regard to both structure and succession. His two main achievements are, I think, the recognition of the Loch Awe Syncline and the separation of the sedimentary complex of the district into two divisions:—the Loch Awe Group and the Ardrishaig Phyllites. It is true that he never vouchsafes a clear statement as to how the existence of the Loch Awe Syncline can be demonstrated; but, for the following two reasons, it seems mere justice to accord to him the credit of the discovery:—

1. It was Mr. Hill who first correlated the Craignish Phyllites, on the north-west side of the Loch Awe outcrop, with the Ardrishaig Phyllites on the south-east.

2. It was he, again, who mapped the Ardrishaig Phyllites across the general strike of the Loch Awe Group, at the northern end of the loch: where, once the mapping has been accomplished, the superposition of the Loch Awe Group upon the Ardrishaig Phyllites may be quite well described as self-evident.

Although Mr. Hill did the lion's share of the work, he had many collaborators as time went on. In the nineties Mr. C. T. Clough mapped the greater portion of the Ardrishaig Phyllite outcrop in Cowal, on the south-east side of Loch Fyne. About the same time the late Mr. R. G. Symes entered the district from the north-west, and became responsible for a limited area in the neighbourhood of Loch Avich. In 1895 Mr. H. Kynaston joined the ranks of the investigators, and surveyed a considerable portion of the district near the northern end of Loch Awe, especially that part which lies on the western side of the loch. His work was brought to a close when he went to the Transvaal in the spring of 1903. Meanwhile Mr. Hill's active co-operation had well-nigh ceased:

for he had been transferred to the English staff in 1897, and most of his time was thenceforward occupied in Cornwall. In 1901 Dr. B. N. Peach came into the district, and, with the late Mr. J. S. Grant Wilson and Mr. H. B. Maufe, carried the survey down the two sides of Loch Craignish; the Craignish peninsula itself fell mainly to Mr. Maufe. Later all three mapped small disconnected areas in the more southern part of the district; Dr. Peach undertook the examination of the Tayvallich peninsula himself, there making a most important discovery to which I shall return presently. In 1904 Dr. Peach left the West Highlands for Ross-shire, and Mr. Clough returned once more to Argyllshire. Mr. Wilson died in 1908, and Mr. Maufe left for Rhodesia in 1910. By this time mapping in the district had already been brought to a close (1906), but the southernmost of the 1-inch maps (Sheet 28), with its explanatory memoir, did not appear till 1911. My own connexion with the district dates from 1902, when I started work south of Loch Crinan. The conditions were very advantageous, as Dr. Peach was making geological history rapidly in those days, and always kept me in touch with his latest results. For a couple of seasons Mr. G. W. Grabham was working on the two sides of Loch Caoilisport, along with Mr. Clough; but Africa claimed him too, and in 1906 he went to the Sudan. In the same year Mr. W. B. Wright also undertook the mapping of a small area east of Loch Caoilisport, thus helping to complete the survey.

Naturally, as a result of so much co-operation, a great advance in our knowledge of the district was achieved. It is the purpose of the present paper to develop two somewhat important points, concerning which it seems to me that conclusions previously arrived at and published by Mr. Hill call for modification:—

1. Dr. Peach has shown that the epidiorites of the region include many volcanic rocks, whereas Mr. Hill regards them all, in the district which he has mapped, as intrusive.

2. I have myself introduced a considerable alteration in the reading of the stratigraphy of the Loch Awe Group.

These two points have a close connexion, for, as a matter of fact, Dr. Peach's discovery of a recognizable volcanic zone afforded a valuable additional clue in the disentanglement of the stratigraphical problem. It is convenient, however, to consider them apart, indicating very briefly the progress of research in each case.

II. The Volcanic Rocks.

In 1903 Dr. Peach discovered unmistakable pillow-lavas (Pl. XXXI) exposed on the coast south of Tayvallich, in association with black slates, limestones, and fragmental rocks like tuffs and agglomerates [13, p. 59]. The discovery came rather late in the day, for by this time all the district north of Tayvallich had already been mapped. Still, there were several records

which at once suggested that Dr. Peach's discovery would have a wide application in the northern part of the region. Extracts from such passages as bear upon this point are given below.

In 1897 Mr. Kynaston noticed that certain 'epidiorite sills,' not very far from the northern end of Loch Awe, showed peculiar structures which he attributed to mechanical deformation [6, p. 62]. In these sills there are, he says,

'numerous elongated and oval masses of the rock, around which the rest of the mass appears to sweep with a kind of flow-structure on a large scale. The whole section gives the appearance of gigantic "augen-structure." This is well seen in the burn at Ardbrecknish,[1] and again south-west of Kilchrenan.'

Dr. Peach, whose attention was drawn to some of these 'augen' by Mr. Kynaston, has told me that he regards them as deformed pillow-structures, an interpretation supported by photographs which may be consulted in the Survey collection (numbered C 772–774).[2]

Three years later Mr. Kynaston, in dealing with the same district, actually divided the epidiorites into two classes, grouping the more vesicular rocks among them as 'lavaform,' although he still regarded them as intrusive [9, p. 34]. Among his lavaform epidiorites are some, the description of which again suggests the existence of pillow-lavas; for we read that a

'rock, seen to the south-west of Kilchrenan, forms hard, roughly spheroidal cores, packed closely together in a dull fine-grained green schist.'

In summing up, he says:—

'We thus have varieties of the so-called "epidiorites," which in hand-specimens and in thin slices under the microscope have every appearance of true lava.'

It must be remembered that Mr. Kynaston left for South Africa in the spring of 1903, the year in which Dr. Peach later on obtained conclusive evidence of volcanic rocks south of Tayvallich. Accordingly, Mr. Kynaston's description in the Geological Survey memoir on the northern part of the district, published in 1908, was written with the idea that, despite appearances, all the epidiorites were really sills. We may note, however, that he supplies us with an additional locality for what one may reasonably interpret as a pillow-lava [16, p. 43]. After referring to a porphyritic vesicular epidiorite 2 miles south-south-east of Portsonachan, that is, on the eastern side of Loch Awe, about 3 miles south of Kilchrenan, he goes on to say,

'Not far from this locality there is a zone of rock, forming part of the same mass, which consists of numerous lenticular patches of a highly amygdaloidal rock embedded in a fine-grained greenish schistose matrix. . . . The rock has strongly the appearance of a highly vesicular basic lava.'

Farther south, about a quarter of a mile north-east of Loch a' Ghille, which lies a mile and a half south-east of Loch Avich,

[1] East of Loch Awe, $2\frac{1}{4}$ miles east-south-east of Kilchrenan.

[2] There is a very fine series of photographs, taken by Mr. R. Lunn, in the Geological Survey collection, illustrating the geology of the Loch Awe district, especially the Tayvallich peninsula.

Mr. Symes had a similar experience [8, p. 62], for he met with an epidiorite outcrop, which he described as follows :—

'The first few feet of this sill lying next to the dark slates present a highly vesicular and amygdaloidal texture. . . . Where the kernels have weathered out the rock is so cellular as closely to resemble a lava, which the rock may possibly have been.'

This observation was made in 1899, and its record constitutes the first published expression of opinion that volcanic rocks may exist in the district. I believe that it is fair to assign no small share of the credit of this observation to Dr. Peach.

It was presently found that this vesicular epidiorite was not an anomaly: for two years later Dr. Peach, the late Mr. Grant Wilson, and Mr. Maufe found it convenient to group the epidiorites of the large district lying between Loch Avich and Crinan Loch into two types—both types, as was the custom of the time, regarded as intrusive [12, p. 129]. One type is

'a fine-grained rock, slaggy and highly vesicular at its margin, sometimes showing an arrangement of phacoids with vesicular outer layer and a non-vesicular interior suggestive of the "pillow-structure" visible in certain lava-flows. Sills of this rock are usually associated with phyllites and limestones, and apparently produce little or no metamorphic action upon the neighbouring sedimentary rocks.'

This absence of special metamorphism due to contact-alteration in the sediments accompanying the 'lavaform epidiorites' is a significant fact; for the regional metamorphism of the district is of so low a grade that contact-alteration accompanying the coarse-grained epidiorites is often very conspicuous. It was, of course, because many of the epidiorites of the region are obvious intrusions that there was such reluctance to admit that any of them might be lavas.

Although Dr. Peach and his collaborators did not re-examine the ground, it is not surprising to find them, in the memoir which appeared in 1909 [17, pp. 43, 45], expressing the opinion that, in the light of the Tayvallich evidence, some of the epidiorites should be regarded as true lavas. In support of this, Mr. Maufe published a very convincing sketch from his notebook of one of the vesicular sheets, showing well-defined pillow-structure [17, fig. 5, p. 45].

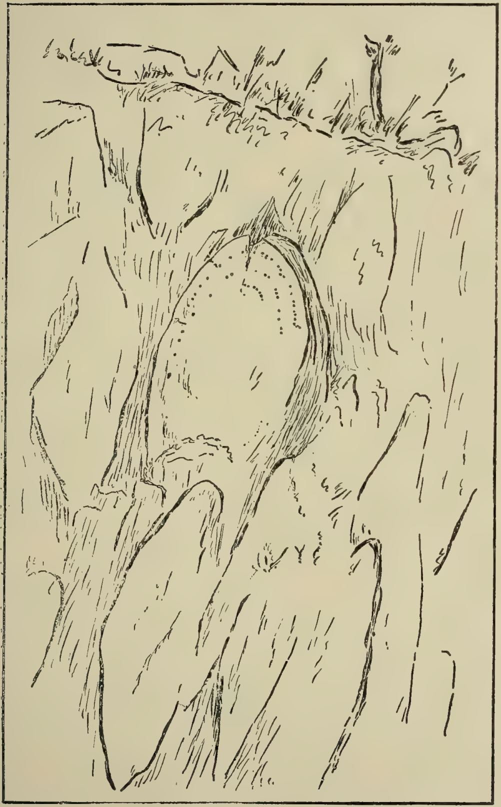
Turning eastwards, we encounter similar evidence, for in 1900 Mr. Hill met with highly vesicular epidiorites in the neighbourhood of Loch Awe. After describing a typical development of these rocks near Inverliver, he adds :—

'Mr. Teall has pointed out the resemblance of these unaltered rocks to the volcanic accompaniments of the Lower Silurian radiolarian cherts in the South of Scotland and elsewhere.' [8, p. 42.]

Dr. Flett has of late greatly added to the significance of this comparison of Dr. Teall's, for he has extended it to include the lava-types of the western region already mentioned [17, pp. 50–56], and also of the Tayvallich country itself [18, pp. 84–96; see also 19]. Dr. Flett has furthermore expressed the opinion that the coarsely-crystalline intrusive epidiorites must be regarded as

genetically connected with the lavaform varieties. This conclusion is likely to meet with fairly general acceptance in regard to the

Fig. 1.—*Pillow-lava, Rudha Barain, western shore of Loch Awe, 1 mile east of Inverliver.*



[The 'pillow' showing concentrically-arranged vesicles measures 1 foot in length by 9 inches in breadth. The interspaces between the 'pillows' are occupied by sandy slate.]

majority of the intrusions, but it will be readily understood that petrological comparison of metamorphic igneous rocks *inter se* is a

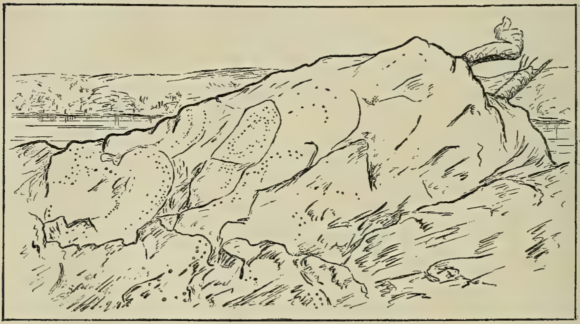
peculiarly difficult field of research, and that the results obtained are often merely tentative.

I may complete this notice, of the accounts so far published of what I take to be the Tayvallich volcanic zone, with a reference to another

'porphyritic epidiorite, which resembles a deformed pillowy lava in which the interspaces between the pillows have been infilled with sediment.'

This last I found in 1905 on the shores of Loch nam Ban, east of Loch Sween [15, p. 92]. Farther north, along the same line of strike, vesicular epidiorites had previously been met with by Mr. Hill and Dr. Peach, and their distribution is such that the Loch-nam-Ban occurrence is linked on with those of the Loch Awe and Loch Avich region.

Fig. 2.—*Deformed pillow-lava, Rudha Cuillin, eastern shore of Loch Awe, a mile and a half east of Inverliver.*



[The 'pillows' are from 2 to 5 feet long.]

It is clear, then, that by 1905 a large body of evidence had accumulated, which was susceptible of the interpretation that Dr. Peach's 'Tayvallich volcanic zone' was widely developed in the precincts of Loch Awe. It was, of course, highly desirable critically to re-examine this old evidence in the light of the new interpretation. An opportunity came with the publication of Sheet 37 and its accompanying memoir [14], an event which rendered the geology of the district accessible to the private worker in an altogether new sense. This occurred in 1905, and in the spring of 1906 I set out in my holiday-time to look into the matter for myself. On the ground, the evidence seems conclusive. The stream-section at Inverliver furnishes a very clear exposure of what, I think, must be regarded as a succession of vesicular lavas; while the shores of Loch Awe, not far away, exhibit the two highly-typical examples of pillow-structure illustrated in figs. 1 & 2 (pp. 285–86), which are exact copies of sketches made on the spot.

On such evidence as this—and it is repeated elsewhere in the neighbourhood—it appears justifiable to recognize the 'lavaform' epidiorites of Loch Awe and its vicinity as true lavas. This opinion is greatly strengthened by another circumstance which became apparent during my visit. There are numerous more or less conglomeratic beds associated with the lavaform epidiorites of the Loch Awe district, and in several cases they contain fragments of epidiorite of lavaform type. As this is a very important point, I shall illustrate it by citing in the following section a few examples of which I have taken definite record. Reference to similar occurrences, already recognized by Dr. Peach in the neighbourhood of Tayvallich, will be found in the Stratigraphical Appendix, § VII, p. 304.

III. Epidiorite-Fragments in Conglomerates near Loch Awe.

Mr. Hill has mapped a conglomerate or conglomeratic series [1] in the district between Glen Aray and Loch Awe. I examined very carefully the wide exposure that occurs half way across between the valley and the loch. The conglomeratic beds have a dark matrix, which may be either siliceous or slaty, and sometimes gritty with quartz- and felspar-grains. The most conspicuous pebbles, ranging up to a foot or more across, consist of pebbly quartzite or grit, and present a water-rounded form with little deformation. They had evidently hardened before they were made into pebbles. With these are associated a great number of small flattened fragments of epidiorite. It takes a good deal of searching to find large lumps, in the light of which the smaller pieces can be interpreted with confidence; but such do occur here and there—some of them very slaggy, and recalling at once in their appearance the pillow-lava series. The epidiorite-pebbles are much more deformed than those made of quartzite.

On the north-western shore of Loch Awe, opposite Innis Stuire (the island through which the line of section AB, Pl. XXXII, passes), the evidence is less certain. A conspicuous outcrop of pure banded black limestone is followed towards the lake by thin gritty limestone, containing big pebbles of quartz and pure limestone. Next comes a thin bed of breccia, exactly like the gritty limestone, save for the addition of very numerous fragments of a pale rock which is apparently epidiorite. This breccia is succeeded by a strong outcrop of gritty limestone, containing fragments of pure limestone, on the extreme shore-line. Finally, there is pebbly quartzite.

Recrossing Loch Awe, one meets with the following section at a lime-kiln, a quarter of a mile due south of Fincharn Castle, which stands on the shore opposite Inverliver. The rocks are

[1] This is the only one of the conglomerates, now dealt with, that it has been found practicable to show in the map, Pl. XXXII.

steeply inclined and often vertical, and their cleavage dips north-westwards at angles ranging from 45° to 30°. The section is given from north-west to south-east, without any suggestion as to the order of original superposition :—

	Feet.
Epidiorite	20
Quartzose slates	15
Epidiorite	4
Slates	3
Gritty limestone with large epidiorite-blocks	5
Pure dark-grey limestone	20
Similar limestone, except that it carries pebbles consisting mainly of quartz: these pebbles are few and scattered, and are at first small; but, farther on, they measure as much as half an inch across	42
Non-porphyritic epidiorite	40
Gap with pure limestone outcrops	30
Pure limestone, dark grey, bedding well preserved	3
Breccia containing very numerous fragments of fine-grained non-porphyritic epidiorite in a limestone matrix, which weathers in honeycomb fashion owing to an abundance of big crystals of black calcite; the matrix also contains numerous large grains of quartz	3
Strongly pebbled dark-grey limestone	150

Fig. 3.—*Breccia containing epidiorite-fragments interbedded between fine-grained limestone and gritty limestone. Limekiln, a quarter of a mile due south of Fincharn Castle, eastern side of Loch Awe, opposite Inverliver.*

[The bedding is steep, the cleavage gently inclined north-westwards. Length of exposure figured = approximately 20 feet.]

The mode of occurrence of the breccia intercalated between pure and gritty limestones is illustrated in the above sketch, fig. 3.

On the two sides of Stronesker, which lies a mile and a half due south of the southern end of the loch, there are important

outcrops of limestone; both outcrops are pebbly and occasionally conglomeratic, with large grains of quartz and felspar and fragments of dark-grey pure limestone. A conglomeratic band east of the stream, east of Stronesker, contains abundant fragments of slaggy and compact epidiorite.

It may be asked how the presence of epidiorite-fragments in the conglomeratic beds of the district had not been recognized long ago. The answer is that they had been missed at first, when there was so much that was new to grapple with; but, in 1900, just at the close of his work, Mr. Hill did begin to realize their existence in certain cases. By this time, however, he had come to regard the intrusive nature of the epidiorites of the district as certain, and consequently interpreted any conglomeratic bed in which he recognized an epidiorite-fragment as a 'crush-conglomerate.' His views are expressed in a paper published in 1901 by this Society [10]. During my traverse in 1906, I did not visit any of the localities which Mr. Hill had described; but, in 1908, I had the opportunity of carefully examining the main example at Creag nam Fitheach, a mile south of the head of Loch Craignish. The breccia in this case consists of irregular blocks of the vesicular type of epidiorite, set in a scanty matrix of gritty limestone [17, pl. vi]. On so controversial a subject it must be admitted that there is room for two opinions. and Mr. Hill's interpretation is supported by the fact that it was adopted and applied to similar examples in the neighbourhood by Dr. Peach, Mr. Grant Wilson, and Mr. Maufe. At the same time, it seemed well-nigh incredible to me, when I saw the Creag-nam-Fitheach exposure, that such a breccia, in which individual clastic grains of quartz and felspar frequently interpose themselves between adjacent blocks of epidiorite, could have originated as a crush-conglomerate. Moreover, before my visit, Dr. Peach had repeatedly told me in conversation that, especially since his recognition of the Tayvallich volcanic group, he had grave doubts concerning the 'crush-conglomerates' of the northern part of the district, although he had for a time admitted their existence.

IV. The Stratigraphy.

In his 1899 paper, published by this Society, and in his subsequent writings for the Geological Survey, Mr. Hill put forward the following interpretation of the Loch Awe sequence:—

Grits and quartzites,
Black slate (locally green),
Limestone.

This he regarded as a descending sequence, modified by local passage of one type of sediment into another. His meaning is best expressed in his own words:—

'Although occupying a general position between the Ardrishaig slates on the one hand and the black slates on the other, the limestone does not rigidly adhere to that horizon, but may occur both within and above the black slate,

and it appears probable that it may sometimes occur within the Ardrishaig slates. Further, the black slates associated with the limestone are often feebly developed and may die out altogether, so that we get the limestone and grits in juxtaposition. Speaking generally, it may be stated that when the limestone departs from the normal type it partakes of the character of the sediment with which it is immediately associated' [14, p. 41].

Again, the black slates

'may occur above, or below, or in the limestone, and sometimes, by gradually becoming more calcareous, pass into the limestone, so that no line can be drawn where the limestone ends and the slates begin' [7, p. 474].

And, lastly,

'the green slates occur on the same stratigraphical horizon as the darker beds with which they are often associated, but their distribution is more local' [14, p. 43].

From the foregoing quotations it is clear that Mr. Hill's classification is somewhat vague. One circumstance which he emphasizes in all his descriptions is the essential unity of the Loch Awe Group. At the same time, he recognized that the deposition of the group was interrupted to some extent by contemporaneous erosion, resulting in the local production of a

'boulder-bed that occurs promiscuously throughout the series, and includes fragments of each lithological type' [14, p. 45].

He regarded it as likely that the 'boulder-bed' belonged to the same general phase of deposition as the coarse grits.

Dr. Peach for several years accepted Mr. Hill's main conclusions, save that he laid considerably more stress on the evidences of local erosion, and referred them all to the period during which the quartzite accumulated [14, p. 56; 17, p. 23]. In applying this view consistently, he was forced to assign many more outcrops of limestone to the quartzite division than had previously been done: for quite commonly the limestones of the Loch-Awe region carry large quartz and felspar-pebbles, exactly like those characteristic of the quartzite, and in many cases rock-fragments too. Here he came into conflict with Mr. Hill's observations: for the latter, in writing of the limestone, steadily maintained that the

'extreme divergences in type may all be met with in the same seam' [14, p. 41].

Another, though minor, point of difference may also be noted: Dr. Peach thought that the grey and green slates and phyllites of the Loch Avich district represented a reappearance of the Ardrishaig Group, whereas Mr. Hill placed them in his Loch Awe Group, regarding them as a local facies of the black slates.

Dr. Peach's position in regard to the relation of the quartzite to the other sedimentary schists was based to a considerable extent upon analogies drawn from other parts of the Highlands, and, although never accepted by Mr. Hill, was adopted by the rest of us who were working at the time in the district. We were, however, not in a favourable position to form a judgment, since, although much of the region had been surveyed, no adequate geological map

had as yet been published. This want was rectified when, as already mentioned, Sheet 37 and its accompanying Memoir appeared in 1905 [14]. My visit to the district in the following spring led me to replace the previous classification of the Loch Awe Group by the following :—

Loch Avich Green Slates and Grits (volcanic rocks in the lower part),
Tayvallich Black Slates and Limestones (volcanic rocks throughout),
Crinan Quartzites and Grits,
Shira Limestone.

Of these zones, the Shira Limestone may be regarded as in part belonging to the underlying Ardrishaig Phyllite Group.

In the 1906 traverse, I found that this new classification held good in the central and eastern parts of the Loch Awe district and also in the Tayvallich peninsula, where I was fortunate enough to obtain clear evidence that the Tayvallich Slates and Limestones structurally overlie the main mass of quartzite. At the same time, I was still ready to believe that Dr. Peach's interpretation would hold without serious modification in the district south and west of Loch Avich, where he had originally developed it in conjunction with Mr. Maufe and Mr. Grant Wilson. I thought it likely, therefore, that the Craignish Phyllites would prove to belong to the Loch Avich division of the Loch Awe Group, and not to the Ardrishaig Group as heretofore supposed. However, this view has been perforce abandoned in the light of further research. On the publication of Sheet 45 with its explanatory memoir, in 1908, I immediately visited the northern part of the district, and in the same year I had the great advantage of a joint traverse with Mr. Maufe, in official time, through the country on both sides of Loch Craignish. The result of this more recent work was to vindicate Mr. Hill's correlation of the Craignish and Ardrishaig Phyllites—a correlation all along accepted by Dr. Peach; and, at the same time, to convince me that the north-western portion of the Loch Awe outcrop was susceptible of reinterpretation in such manner as to bring it into line with the rest of the district. About this time Dr. Peach realized the cumulative force of the evidence acquired, and so the two of us were able to co-operate in the description of the Tayvallich peninsula given in the memoir dealing with Sheet 28, which appeared in 1911. Since then I have not revisited the ground, except for a few days in 1912, when I returned to Loch Awe, and, among other things, examined the northern termination of the outcrop of the Loch Avich Slates and Grits.

Before giving the evidence for the new interpretation, I think it better to state quite clearly that it has not gained acceptance from Mr. Hill. We paid an official visit together to the Tayvallich peninsula in the spring of 1909, but Mr. Hill did not find the evidence presented to him sufficiently convincing to shake his old-established faith. His views upon the matter are set forth in the Survey Memoir [18, p. 61], where he indicates that his interpretation of the Loch Awe sequence has been influenced by the fact

that, in the neighbourhood of Dalmally, there is undoubtedly an extensive development of black slate or schist, and subordinate limestone interposed between the Ardrishaig Phyllites and a pebbly quartzite, of which last he speaks as the Loch Awe Grit. I have purposely excluded these northern rocks from the scope of the present paper, since I consider their relation to the Loch Awe Group a very much more difficult question to decide than is the sequence of the rocks actually included within the Loch Awe Syncline.

And now for the evidence upon which the present subdivision of the Loch Awe Group is based. It may be summarized under various headings:—

(1) Mr. Hill's contention that the Loch Avich Slates and Grits form part of the Loch Awe Group is justified by the nature of the grit or quartzite intercalations which accompany the slates: many of these agree precisely in character with the rocks of the main Crinan Quartzite.

(2) At the same time, the Loch Avich Slates and Grits furnish a definite stratigraphical horizon, as maintained by Dr. Peach. This much is apparent from the fact that their outcrop occupies a symmetrical position in the centre of the Loch Awe Syncline, and is, in its own central part, characterized by a complete absence of epidiorite.

(3) There is fairly conclusive direct evidence that the Loch Avich Slates and Grits structurally overlie all the other rocks of the Loch Awe Syncline. At the northern end of their outcrop, on the east side of Loch Awe, there is a very definite boundary between the slates and grits which form the central exposures and the surrounding epidiorites. In a north-easterly direction the sedimentary outcrop narrows and disappears, in a manner that almost certainly indicates the existence of a fold. It was obviously important to ascertain whether the disappearance of the sediments is the accompaniment of a north-easterly or of a south-westerly pitch: whether in fact the fold, if such there be, is anticlinal or synclinal. On visiting the exposure, it was found that grits are prominent where the sedimentary outcrop is wide, that is, towards the loch. They consist of strong pebbly quartzo-felspathic rocks with obscure bedding, so that their structure is not clear. Appearances suggest, however, that they occupy a syncline having a triplex termination. After the grit ceases, a considerable thickness of green cleaved mudstone with widely-spaced, faintly-marked bedding occupies the whole breadth of the narrowing sedimentary outcrop, and persistently shows south-easterly pitches, in accordance with the view that the outcrop is of synclinal nature.

(4) The Tayvallich Black Slate and Limestone division has an assemblage of characters which distinguishes it from the Shira Limestone. Among these characters the importance of black slate

in the Tayvallich Division, together with the frequent occurrence of pebbly and conglomeratic beds, may be noticed at once. Although Mr. Hill did not attach stratigraphical importance to these differences, he did not fail to record them [14, pp. 50–51]. Thus, in describing the district lying between Loch Fyne and Loch Awe, he says that the limestone, where it crops out at the margin of the Loch Awe Group—that is, according to the new interpretation, in the Shira position,—

'although usually sandy, rarely exhibits the coarse gritty character seen further to the north-west. There is either an entire absence of black slate, or it occurs in very limited amount. Further, the boulder-bed has not been observed at that margin, so that, speaking broadly, the occurrence of the boulder-bed, the gritty limestone, and black slate in appreciable quantity appear to hang together. Moreover, the marginal limestone, where not associated with black slate, is seldom of the dark graphitic hue which it assumes when in association with well-developed black slate.'

To these differences it may be added that the Tayvallich Volcanic Zone, with its accompaniment of breccias containing epidiorite-fragments, is very strongly developed in the Tayvallich Slates and Limestones, and in the adjacent portion of the Loch Avich Division, but is completely unrepresented in connexion with the Shira Limestone.

(5) The associations of the Tayvallich Slates and Limestones distinguish this division from the Shira Limestone. The Tayvallich Division in the neighbourhood of Loch Awe is interposed between the Loch Avich Slates and Grits, in the centre of the syncline, and the surrounding Crinan Quartzite. The Shira Limestone, on the other hand, is admittedly interbedded between the Crinan Quartzite and the Ardrishaig Phyllites beyond. It is claimed that the differences, cited in this and the preceding section, are a proof of the stratigraphical distinctness of the two divisions.

(6) Structurally, the Tayvallich Slates and Limestones lie above the Crinan Quartzite, while the Shira Limestone lies below it. This structural proposition is, of course, quite distinct from the stratigraphical proposition argued above. It is based upon three main sections:—

(6 *a*) The relation of the Tayvallich Slates and Limestones to the Crinan Quartzite is exposed to perfection in the Tayvallich peninsula, and has been described by Dr. Peach and myself in the Survey Memoir [18, pp. 65–68]. The reader is referred to this description for details, which are illustrated by a text-map on the scale of 3 inches to the mile. The following are the main conclusions:—There is no sharp line of separation between the Tayvallich Division and the Crinan Division of the Loch Awe Group: the two are united by an intermediate zone in which there is conspicuous interbedding of the various rock-types—slate, limestone, and quartzite, any of which may assume a conglomeratic facies. But, despite the transition-zone, the two divisions have a well-marked individuality, and the Limestone-Slate Division, with its

associated lavas, clearly overlies the Quartzite Division, with its intrusive sills:—

'The rocks of the area are sharply folded, in the manner usual in the region, about axes trending north-north-east and south-south-west, so that the order of superposition of the beds is only made apparent owing to a marked pitch of the axes of the folds towards the south-south-west in the northern part of the area. The Quartzite Group is thus carried to the southward underneath the overlying slates, limestones, and volcanic rocks, which cross the peninsula from the Sound of Jura inwards to the Linnhe Mhuirich [1] in the form of an escarpment facing the north, complicated by minor folding.' [18, pp. 65–66.]

(6 *b*) The Crinan Quartzite is less strongly developed in the north-western portion of the Loch Awe Syncline than elsewhere, and some of the mapping north of Kilchrenan may be open to criticism, especially as the ground is locally obscured by Glacial deposits. Still, I have satisfied myself as to the essential accuracy of Mr. Kynaston's mapping in this locality, and have found independent evidence for a descending structural sequence from the Tayvallich Division right down to the Ardrishaig Phyllites. Mr. Kynaston has traced a conglomerate—which may be confidently correlated with the Glen Aray Conglomerate already described—in a curved outcrop past Kilchrenan, across the general strike of the folding, down to the shores of the loch. The exposures are discontinuous, it is true, but there can be no doubt that they all belong to a single horizon. On the south is an expanse of epidiorite, from beneath which the conglomerate emerges, owing to an obvious, though gentle, south-westerly pitch.[2] On the north and west is a tract of black slate and limestone, sometimes pebbly. All these sedimentary rocks, including the conglomerate, evidently belong to the Tayvallich Division, although the stratigraphical simplicity is marred to some extent by the local presence of a strong intercalation of pebbly quartzite occupying part of the interval between the conglomerate and the first important limestone. Beyond, again, is a belt of scattered quartzite-exposures, representing, I take it, the Crinan horizon. This belt is in turn limited by a limestone outcrop, or series of outcrops, which certainly must be referred to the Shira position, and as certainly overlies the Ardrishaig Phyllites of the slopes overlooking the loch.

(6 *c*) In the previous paragraph it has been noticed that the Shira Limestone and other members of the Loch Awe Group clearly overlie the Ardrishaig Phyllites on the north-west side of Loch Awe. This feature is extremely well shown again in the country on the opposite side of the loch. It has already been stated that the recognition of this important structural relation, the superposition of the Crinan Grits and Shira Limestone upon the Ardrishaig Phyllites for miles across the general strike of the folds, is probably responsible for Mr. Hill's belief in the existence of the Loch Awe Syncline.

[1] The western arm of Loch Sween.

[2] The agreement of this evidence with that already adduced in regard to the structural position of the Loch Avich Slates and Grits is complete.

The examples given above to illustrate the structural relations of the various members of the Loch Awe Group one to the other, and to the Ardrishaig Phyllites below, might doubtless be supplemented, with very little trouble, by further investigation. At the same time, they are regarded as sufficient in themselves. The reader must be warned, however, that he will find in the previous literature many references to 'folds' pitching in this direction or in that, to 'anticlines' and 'synclines,' to 'inliers' and 'outliers,' the existence of which, if established, would be fatal to the present interpretation. As a matter of fact, many of these folds, despite their definite designation, are essentially subjective, having been based upon the current reading of the stratigraphical succession. The geological literature of the Highlands has suffered greatly in the past from this subjective presentation of tectonics, for there are very numerous descriptions in which observation and inference have not been at all clearly differentiated. There can be little doubt that this indirect method of approaching tectonics owes much of its fascination to the success with which Prof. Charles Lapworth employed graptolitic zones in the elucidation of the structure of the Southern Uplands. Another point must be borne in mind in dealing with the Loch Awe sequence. The various rock-types, although sufficiently separated to allow of the subdivision of the group, are quite certainly interstratified to a very considerable extent. Thus it happens that in some sections we find folds exposed wherein black slate and limestone clearly underlie quartzite, and in others precisely the reverse. Such sections, revealing partial sequences, may prove of great service in working out the structure of the locality in which they occur; but, taken by themselves, they throw no light whatever upon the structural relationships of the major subdivisions of the Loch Awe Group.

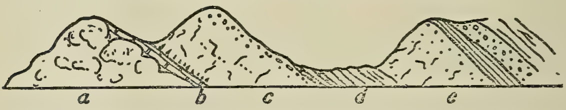
(7) In the Scottish Highlands one should never assume that the order of structural superposition now obtaining is the same as the original order of stratigraphical superposition. In the Loch Awe Syncline, however, there is good reason to believe that the two are in agreement. This evidence is afforded at two localities.

(7 *a*) At Kilmory Bay Mr. Grant Wilson found that the Ardrishaig Phyllites dipped steeply beneath a conglomeratic grit marking the base of the Loch Awe Group [18, p. 64]. The grit is, for the greater part, a pebbly quartzite with bands of fine conglomerate dispersed at intervals throughout. A feature of the conglomerate-bands, which impressed me very strongly, was that each of them has a well-defined base and an ill-defined top; the pebbles start suddenly in full force at the bottom, and then gradually decrease in number upwards, allowing the conglomerate-bands to merge, in this direction, with the containing quartzite. The tops and bottoms of the conglomerate-seams are thus strongly contrasted, and the contrast is of the type with which one meets, not uncommonly, in unfolded conglomerates. In fact, it is exceedingly difficult to escape the inference that these conglomeratic seams are 'right way up.'

If so, it follows that the Loch Awe Group is a later formation than the underlying Ardrishaig Phyllites, unless it has been thrust into its present position, which is a most unlikely alternative.

(7 *b*) Evidence pointing in the same direction had previously been obtained by Dr. Peach. It has already been noticed that the Tayvallich lavas cross the peninsula with an escarpment facing north. At the foot of the escarpment are limestones and slates belonging to the Tayvallich Division, and from beneath these emerges a passage-zone, followed eventually by the main mass of the Crinan Quartzite. If it can be definitely determined whether the lavas in the escarpment are 'right way up' or no, then the original order of superposition of the various divisions of the Loch Awe Group follows as a corollary. This is exactly what Dr. Peach has succeeded in doing, with very fair certainty. Fig. 4, taken from Dr. Peach's description, shows the nature of the escarpment where it reaches the sea. The important point for our present purpose is the marked difference which exists between the tops and bottoms of the two lowest lavas.

Fig. 4.—*Volcanic section south of Port an Sgadain, western coast of Tayvallich Peninsula; after B. N. Peach.*



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Of these, the lowest of all (*a*, fig. 4) is about 20 feet thick, with an irregularly-jointed lower portion, containing few gas-cavities, and a remarkably rugged portion, 8 feet thick, consisting entirely of vesicular pillow-shaped masses. The second lava (*c*, fig. 4) is a highly vesicular rock, 15 to 20 feet thick, with numerous 'pipe-amygdales' in its lower portion set approximately at right angles to the base, and a porous upper surface. I agree with Dr. Peach in his opinion that this volcanic section has entirely the appearance of being 'right way up'; and from this it follows that the structural sequence in the Loch Awe Syncline, in all probability, agrees with the original order of superposition.

V. The Structure and the Metamorphism.

I have already alluded to Macculloch's early recognition of the fan-structure which roughly marks the central line of the Loch Awe Syncline. This structure seems to become vague in the northern part of the Loch Awe district; but Mr. P. Macnair is probably justified in regarding it as the equivalent of the Ben-Lawers fan farther north-east in the Central Highlands [11, p. 207

and map facing p. 224]. It has long been claimed that Ben Lawers is, in the main, synclinal in structure, and—without entering further upon a subject which needs very careful consideration—it may be admitted, as a working hypothesis, that the Loch Awe Syncline is in part continued through Meall nan Tighearn towards the north-east along the Ben Lawers line. At the same time, it is fairly certain that the Loch Awe Syncline is also continued north-north-eastwards, where it would seem to reappear as the Glen Creran Syncline on the other side of the granitic complex of Etive. According to this view the Loch Awe Syncline bifurcates, giving rise to the Ben Lawers and Glen Creran branches, which are separated by the Glen Orchy Anticline recently described by Mr. M. Macgregor and myself [20].

It is a familiar fact that the Loch Awe Syncline includes schists of an unusually low grade of metamorphism. This point has been very clearly brought out in Mr. Hill's 1899 paper, so often referred to already. At the time he contented himself with a description of the phenomenon, without venturing upon any explanation of it. Later, however, he has offered two distinct suggestions of a possible connexion between the metamorphism and the structure of the district. In the Memoir on Sheet 37 [14, pp. 74, 75], he connected the low metamorphism of the rocks along the central belt with their variable inclination, which latter he regarded as an indication of a less compressed folding in this position than on either side, where steady inward dips predominate. Subsequently, in the Memoir on Sheet 28 [18, pp. 83, 84], he replaced this explanation by one which seems much more likely to be fruitful. Regional metamorphism, he suggests, is connected both with dynamic action and with depth-temperature; and accordingly the degree of metamorphism is likely to correspond, in a broad way, with the depth at which the deformation was achieved.

There is, of course, nothing new in Mr. Hill's suggestion that depth may have had a determining influence in metamorphism, for this is one of the oldest ideas in Geology. But the theory is none the worse for being old, and its application in a concrete case is exceedingly welcome. Its probability is considerably enhanced by the following consideration. On the south-east, the Loch Awe Syncline is flanked by the Cowal Anticline, which Mr. Clough has given good reason to believe is an anticlinal structure affecting schists already bent into great recumbent folds. Just as the axial belt of the Loch Awe Syncline is characterized by low-grade metamorphism, so that of the Cowal Anticline is characterized by high-grade metamorphism. In discussing this phenomenon Mr. Clough, in 1897 [5, p. 91], pointed out that the rocks at present exposed in the centre of the anticline

'must, before the ridging up, and subsequent denudation, have been lying under a much greater thickness of rock, and therefore presumably exposed to higher temperatures, derived from the earth's internal heat, than those now occurring far away on the flanks.'

In this opinion Mr. Clough was, to some extent, anticipated by

Nicol in a paper read before this Society in 1862: for, as Gunn has pointed out, Nicol seems to attribute the high metamorphism of the rocks exposed along the axis of the Cowal Anticline to their having been

'taken down into those interior regions of the earth's crust where the chief laboratories of metamorphic action are situated' [3, p. 199].

But to Mr. Clough belongs the particular credit of a new conception in Highland geology. For, according to his reading of the structure, the depth of the cover, under which the highly metamorphic rocks of Cowal crystallized, was not directly determined by the position of these rocks in an original stratigraphical sequence, but by the degree to which they had been buried beneath superincumbent folds. This conception is likely to prove of wide application, and I may conclude by suggesting that it may render more intelligible the progressive metamorphism noted by Mr. Hill north-east of Loch Awe. It has already been mentioned that near Dalmally there are black schists, limestones, and pebbly quartzites which Mr. Hill refers to the Loch Awe Group. They are, as the same author correctly points out, much more metamorphic than their supposed equivalents round about Loch Awe. Now, it so happens that a consideration of the relation of these rocks to the Glen Orchy Anticline and the Loch Awe Syncline renders it quite certain that, whatever their stratigraphical position, they structurally underlie the Ardrishaig Phyllites: that is, they are on a definitely lower rung of the tectonic ladder than the Loch Awe Group at Loch Awe.

It is to be hoped, however, that the 'depth principle' will not be pushed too far. There are already difficulties foreshadowed in its application, even in the West Highlands: for the metamorphism continues of low grade on the north-west side of the Loch Awe Syncline, as, for instance, in Islay, across the Sound of Jura. There are probably many factors at work, and one must always remember that great earth-movements may be accompanied by little metamorphism, when the tendency is, as in the North-West Highlands, to superpose metamorphic rocks upon non-metamorphic. The evidence which Mr. G. Barrow has adduced to connect the regional metamorphism of the Highland schists with certain widespread granitic intrusions must also be borne in mind [4 & 21].

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VII. APPENDIX ON THE STRATIGRAPHY.

IT is not the purpose of this paper to replace the detailed account of the district already given in the Geological Survey Memoirs. At the same time, the following epitome of the stratigraphy is offered for the convenience of workers in other parts of the Highlands. This epitome is a compilation made in the light of personal knowledge. The whole district has been examined, except the part situated in Cowal and, northwards, from Glen Shira to Meall nan Tighearn. The Shira Limestone is dealt with more fully than the other divisions, as it is impossible to extract an altogether satisfactory account of it from the descriptions heretofore published; the differences, however, are all concerned with matters of detail.

The Ardrishaig Phyllites and Erins Quartzite.

The Ardrishaig Phyllites of the Loch Fyne and Craignish districts consist of soft greenish-grey phyllites and phyllitic mica-schists, in many parts containing calcareous lenticles half an inch or less thick. Intermixed with these lenticles are occasional thicker outcrops of pale-yellow, buff-coloured, and white limestone; and also bands of compact fine-grained quartzite, often slightly calcareous.

Small grains of blue quartz can at times be recognized in the siliceous bands, while conglomeratic seams have been described from the Loch Caolisport district by Mr. Clough and Mr. Grabham [18, pp. 53, 54], and from an island in Loch Craignish by Mr. Maufe [17, p. 13]; but such occurrences are quite exceptional.

In Cowal Mr. Clough has found a convenient lower limit to the Ardrishaig Group in an outcrop of graphitic mica-schists, with thin impure graphitic limestones and calcareous quartzites. This assemblage is sometimes spoken of as the St. Catherine's Graphite-Schist. Beyond comes the Garnetiferous Mica-Schist

Group, a non-calcareous mica-schist series, with many gritty intercalations in which pebbles can often be recognized. The most conspicuous feature of the Garnetiferous Mica-Schist of the Loch Fyne tract is the abundance of garnets, but this character fails towards the south-west. The garnets, where present, are frequently accompanied by actinolite.

Towards the north-east, in the Loch Fyne district, the St. Catherine's Graphite-Schist has not been mapped outside of Cowal; but its presence has been recorded by Mr. Hill at one or two points between Loch Fyne and Meall nan Tighearn. It is probable, indeed, that the division-line laid down on the map to separate the Ardrishaig Phyllites and the Garnetiferous Mica-Schist, in this part of the area, follows an approximately constant horizon.

Towards the south-east it is doubtful whether the St. Catherine's Schist persists or no. A remarkable change of stratigraphy is encountered in this direction: for a thick fine-grained quartzite makes its appearance, situated in a general way between the Ardrishaig Phyllites and the Garnetiferous Mica-Schist. It is quite certain that this quartzite, the Erins Quartzite as it is called, belongs in part to the Ardrishaig Group, since its development has been followed, more or less, stage by stage. What is uncertain is, whether any considerable proportion of it is equivalent to the Garnetiferous Mica-Schist farther north. A thin grey phyllitic division, the Stronchullin Phyllites, divides the Erins Quartzite into two roughly equal portions; and in it occurs a band of graphitic phyllite, which Mr. Clough suggests may be correlated with the St. Catherine's Graphite-Schist [18, p. 9]: this would relegate the lower half of the Erins Quartzite to the Garnetiferous Mica-Schist position. Mr. Hill, on the other hand, considers that virtually all the Erins Quartzite belongs to the Ardrishaig Group. The two portions of the Erins Quartzite are much alike; pebbly beds are rare, until the south-eastern border of the division is approached.

The quartzite is very slightly calcareous, where tested, and one or two bands of cream-coloured and grey limestone, several feet thick, are found near its north-western limit; even more important beds of grey limestone occur near its south-eastern margin.

The Shira Limestone.

This limestone is a comparatively thin and inconstant division. On the east side of the Loch Awe Syncline it is not appreciably developed south of the Crinan Canal, connecting Crinan Loch with Ardrishaig. North of the canal, however, the limestone is probably continuous, although, not unnaturally, it is shown on the map as having a broken outcrop.

A very good section is afforded by the River Add, which crosses the course of the Shira Limestone 5 miles north-north-east of Ardrishaig. The limestone occurs here in massive, cream-coloured, banded sandy beds, which effervesce with acid; some of the layers merge into calcareous quartzite. On the east it is separated by a

band of epidiorite from typical grey and green phyllites; on the west it is followed almost directly by massive beds of fine-grained grit with, at first, intercalations of grey-green phyllites of Ardrishaig type. When the phyllitic beds cease the fine-grained grits are so massive that their bedding is not easily discerned. There is no doubt at all that these grits, or fine-grained pebbly quartzites, belong to the Crinan Division.

I have seen very little of the junction-line between the Ardrishaig and Loch Awe Groups, from this point north-eastwards to the wide outcrop of limestone shown on the map (Pl. XXXII) 15 miles north-east of Ardrishaig. Here a visit made it obvious that an important limestone separates the Ardrishaig Phyllites from the Crinan Quartzite. It has the same characters as in Glen Shira—the type-locality with which I shall deal in detail presently.

Again, until Glen Aray is reached, I have no personal knowledge of the Shira Limestone. In Glen Aray that rock is involved in a porphyry intrusion, but its original characters are not destroyed. It consists of a thick mass of limestone weathering to a cream colour, with pale-grey fracture, and is much split up by partings of pale-grey phyllite. North-west of the porphyry is alluvium; but the first rock seen in the valley-bottom is massive somewhat pebbly quartzite, associated with a thin band of cream-coloured limestone.

Capital exposures are afforded by the tributary burns draining from the west into Glen Shira. The second burn south of Drimlee, 5 miles north-east of Inveraray, may be cited as typical. The greater part of this magnificent section, as one ascends from the Shira, is occupied by greenish-grey silvery phyllites. At first, a homogeneous mass of these phyllites is encountered, scarcely interrupted except by igneous rocks: fully three-quarters of the section is of this type. A change is ushered in by the appearance of several well-marked, fine-grained quartzite-bands. Above this, beds, ribbons, and lenticles of cream-weathering sandy limestone, grey and cream-coloured on the fractured face, are continually appearing intercalated in the phyllites. Where numerous, they give added power of resistance to the whole, and the stream rushes across their outcrop in a series of picturesque cascades. The proportion of limestone to phyllite is, as a rule, not very high; but, looking down upon the exposed dip-slopes above these waterfalls, the cream-coloured backs of the limestone-beds make a very conspicuous feature. This type of sedimentation prevails right up to the base of the Crinan Quartzite, save that strong beds of grey sandy limestone, intercalated with grey phyllite, occur in contact with the quartzite. In these dark limestones one has a foretaste of the carbonaceous character so prevalent in the Loch Awe Group. In the sections which remain to be described, the Shira Limestone exhibits this character much more strongly; and it is on this account that the division is regarded as transitional between the Ardrishaig and the Loch Awe Groups.

I have not followed the Shira Limestone continuously in its

curving outcrop leading from Glen Shira to Loch Awe, but a visit to the exposures 2 miles east of the loch showed that cream-coloured and blue-grey limestones are both well developed. Nearer the loch, in a stream crossed by the main road, a section is met with consisting largely of blue, compact, thinly-bedded limestone, with bands of grey slate and more siliceous material. The limestones here are very like many in the Tayvallich position, but the associated slates are never black. The interposition of this exposure between the Ardrishaig Phyllites and the Crinan Quartzite is fortunately quite clear, although the latter division is not very strongly developed.

The grey facies of the Shira Limestone continues west of Loch Awe. The part of the outcrop which approaches the escarpment of the unconformable lavas of Old Red Sandstone Age needs re-examination: it is possible—as the Crinan Quartzite is not in strong force—that I have locally confused Shira and Tayvallich Limestones, for black slate occurs with the limestone not far east of the lava escarpment. The matter is a subsidiary detail, so far as the present paper is concerned, but is of importance to anyone who attacks the problem of the black schists and pebbly quartzites of the Dalmally neighbourhood.

The next exposures to be noticed are on the west side of the Loch Awe syncline, a mile east of the head of Loch Melfort. Here the Shira Limestone is in two beds, separated by a thick epidiorite sill and some green phyllite. The lower band, as exposed near a lime-kiln west of a loch known as Loch Pearsan, on the borders of Sheets 36 and 37 of the Geological Survey 1-inch map, is a well-bedded grey limestone, 12 feet thick. It graduates upwards into calcareous quartzite, with small but recognizable pebbles. In this is a layer of fine-grained pebbly limestone containing limestone-fragments. The upper band, as seen on the northern and southern shores of Loch Pearsan, is a grey-banded limestone with some thin seams of black slate. Here, then, is the Shira Limestone exhibiting —in a very feeble manner, it is true—the pebbly nature and the association with black slate which are so emphatically characteristic of the Tayvallich Division.

Southwards for some distance the Shira Limestone has been recognized in places as a belt of calc-silicate-hornfels, resulting from the metamorphism induced by a small granite-boss. Its outcrop is not shown on the geological maps until, south of this granite, at the head of the alluvium deposited by the river leading into Loch Craignish, its position is marked in the field by three prominent bands of dark-grey limestone separated by grey phyllites; the zone extends here for about a quarter of a mile west from the margin of the Crinan Quartzite.

Beyond this, towards the head of the loch, one observes occasional exposures of dark-grey limestone; but the division is mostly obscured by alluvium, and no attempt has been made to continue its outcrop on the map. I searched such exposures as occur for black slate, but quite in vain.

The late Mr. Grant Wilson has pointed out [17, p. 24] that

'dark crystalline limestone, accompanied by dark phyllites, occur along the eastern shores of Eilean Righ and Eilean Macaskin in Loch Craignish.'

These island-exposures belong, according to their geographical position, to the Shira Division, but I have had no opportunity of visiting them.

The Crinan Quartzites and Grits.

This division consists for the most part of pebbly grits, many of them sufficiently quartzose to deserve the name 'quartzite.' The texture varies from bed to bed, and from place to place. Often the rocks are very coarse, with large grains of blue or white quartz and fresh felspar. Dr. Flett, in summarizing what is known of the felspar-pebbles of the Loch Awe Group, says that microcline, orthoclase (often perthitic), and oligoclase are found in decreasing order of abundance [18, p. 58]. The coarser grits are sometimes definitely conglomeratic, carrying fragments of slate, limestone, and grit. Such rocks are less frequently found in the basal portion of the division, next to the Shira Limestone, than higher up. Mention has already been made, however, of the conglomeratic base of the quartzite at Kilmory Bay. Grant Wilson states [18, p. 65] that inland the conglomerate

'maintains its characters for a distance of about 4 miles along the strike.'

Another instance of a similar nature was encountered by Mr. Kynaston in a stream known as Allt Fearna, 3 miles south-west of Dalmally. The base of the Crinan Quartzite, resting here upon grey silvery phyllites with limestone-bands, in the Shira position, is coarse and pebbly, and contains numerous fragments identical in type with the underlying limestone [16, p. 28].

While the dominant rock in the Crinan Division is pebbly quartzite or grit, there are numerous intercalations of slate and limestone of varying character. As an example, one may cite excellent exposures of grey slate and repeatedly interbedded fine-grained quartzite and grey sandy limestone at Ardnoe Point, and for 3 miles southwards along the shores of the Sound of Jura. Similar beds occur along the eastern coast of Loch Craignish, and have been recognized inland at many places; but they are not sufficiently differentiated to be mapped out separately as a sub-division of the Crinan Quartzite.

The Tayvallich Slates and Limestones.

This division is connected with the Crinan Grits and Quartzites by a transition-zone, in which there is marked interbedding of black limestone, black slate (with subordinate grey slate), and pebbly quartzite. Even in the heart of the division beds of pebbly quartzite are of not infrequent occurrence, and on occasion give rise to massive outcrops. The predominant rocks of the division are black slate and limestone, very intimately associated—so much so that it has been impossible, in many cases, to show them both on the map.

The limestones are generally black or dark blue, and are often of very considerable thickness. In crystalline texture they vary from fine to coarse, some occurrences being made up for the greater part of crystals of black calcite a quarter of an inch across. Many beds are strongly pebbled, with large grains of quartz and felspar, identical with those that occur in the Crinan Quartzite. In such cases pebbles of fine-grained limestone, slate, and epidiorite are not infrequently found. The slates of the group and the quartzite intercalations also not infrequently assume a conglomeratic facies.

Two conglomerates, the Glen Aray and the Loch-na-Cille Conglomerates, are particularly conspicuous, and have been indicated on the appended map (Pl. XXXII). One, the Glen Aray Conglomerate, has already been described in some detail in its outcrop between Glen Aray and Loch Awe (p. 287). West of Loch Awe, in the neighbourhood of Kilchrenan, it retains the same characters as in Glen Aray, except that (so far as I could see) it no longer carries epidiorite-fragments. The most abundant boulders are pebbly quartzite, but Mr. Kynaston has made the very interesting discovery of granophyre- and felsite-pebbles in it [16, p. 31].

The Loch-na-Cille Conglomerate, much farther south, was detected by Dr. Peach [18, p. 71]. It is extremely full of fragments of slaggy epidiorite, and also contains numerous pebbles of felsite, or porphyry, and quartz-syenite. Dr. Flett [18, p. 75] has investigated the petrology of the pebbles, and has found that the syenites are of the same type as those that occur in the conglomerates of Schiehallion, Islay, and the Isles of the Sea (Garvellach Isles), long ago described and compared by Macculloch [1, pp. 159, 249]. It is an interesting circumstance that the source of these quartz-syenite boulders is quite unknown.

Further careful search might quite likely reveal the presence of similar felsite, and perhaps even quartz-syenite, pebbles in several other conglomeratic beds of the Loch Awe district. At present, there are only two other instances of the kind known: Mr. Kynaston has recorded felsite-pebbles from a conglomeratic limestone, shown on the map (Pl. XXXII) as an isolated outcrop east of Loch Awe and 3 miles south of Kilchrenan [16, p. 31]; while Mr. Maufe has also found felsite in a conglomerate near Ormaig, about a mile south of the head of Loch Craignish and half a mile in from the coast [17, p. 37].

In the district dealt with in the foregoing pages these foreign pebbles are all found in conglomerates within the Tayvallich Division of the Loch Awe Group. It would be rash, however, to assume that this statement holds true throughout the Highlands and Islands of Scotland.

The Loch Avich Slates and Grits.

In this division there are considerable masses of well-bedded, green, cleaved mudstones; these alternate with fine-grained quartzose beds, sometimes containing sandy calcareous nodules

and layers, and also with thoroughly pebbly quartzites or grits like those of the Crinan Division. It is difficult to form an opinion as to the relative abundance of slates and siliceous rocks in the group as a whole, but I think that the former are in excess. The grits are not infrequently conglomeratic.

The Tayvallich Volcanic Zone.

Dr. Peach's 'Tayvallich Volcanic Zone' is situated within the Tayvallich Slates and Limestones and the lower part of the Loch Avich Slates and Grits. The lavas are distinguished by their vesicular character, fine-grained texture, and not infrequent pillow-structure, together with their failure to induce contact-alteration. Characteristic tuffs and agglomerates are more or less absent, but conglomeratic beds containing fragments of vesicular epidiorite are common. Certain felspathic beds in the Tayvallich Peninsula have been interpreted as crystal-tuffs.

As already stated, Dr. Flett [18, p. 84] has made a careful petrographical examination of the lavas. He has referred them to the spilite group, and shown that their felspar is always albite; their ferromagnesian constituent is chlorite, not hornblende.

The Epidiorite Intrusions.

The epidiorite sills are of doleritic texture, where not much sheared, and often show coarse ophitic structure in their central portions. In not a few cases they obviously transgress the bedding of the associated sedimentary schists, and also very frequently produce remarkable contact-alteration.

Under the microscope they are seen to consist essentially of hornblende and plagioclase, which Dr. Flett has found to be albite. The presence of chlorite, with much carbonate, in the lavas, and of hornblende, with comparatively little carbonate, in the intrusions, has led Dr. Flett to the view that the lavas were already much decomposed before they were folded, while the intrusions were fresh [18, p. 88].

Occasional leucocratic varieties are met with among the intrusive epidiorites. Their petrology has been described by Mr. Kynaston [16, p. 44] and Dr. Flett [17, p. 53, & 18, p. 91]. In one case micropegmatite was found to occur locally; in other instances the intrusions proved to have bostonitic affinities. It must be realized that these leucocratic rocks are extremely scarce.

EXPLANATION OF PLATES XXXI & XXXII.

Plate XXXI.

Pillow-lava, An Aird, western coast of Tayvallich Peninsula. Reproduced by permission of the Controller of H.M. Stationery Office, from Dr. B. N. Peach's account of the Tayvallich volcanic rocks [18, pl. iii, facing p. 59]. (See p. 282.)

PLATE XXXII.

Generalized geological map of the Loch Awe District, based upon Sheets 28, 29, 36, 37, & 45 of the 1-inch map of Scotland issued by H.M. Geological Survey; revised and reduced by the author. Scale: 4 miles=1 inch, or 1 : 253,440.

DISCUSSION.

The SECRETARY read the following remarks, received from Mr. J. B. HILL:—

'In a paper communicated to the Geological Society in 1899 I described the Loch Awe Group, the members of which consist of limestone, black slate, and quartzite, the latter forming the top of the sequence. Black slate and limestone are not, however, confined to those horizons, slate often occurring higher up in the series among the quartzite, and limestone likewise appearing at other horizons. These occurrences beyond the main bands I nevertheless regarded as local and of limited continuity.

'In the Tayvallich peninsula the Author has described a limestone band above the quartzite; and the question arises whether that band is local in character, or whether it represents a persistent band marking a definite horizon in its passage across the Highlands. The latter interpretation would imply that not only was there a definite horizon of black slate and limestone below the quartzite, but a corresponding succession above the quartzite. In the Loch Awe area, reduplication by folding is so pronounced a characteristic that the hypothesis of a double sequence must be viewed with suspicion, and needs strong evidence to support it.

'If, however, the pillow-lavas of the Tayvallich peninsula were represented in the Loch Awe basin in association with the limestones of that area, there would be some grounds for placing that limestone above the quartzite, as such lavas have not been detected below the latter at the margin of the Loch Awe Group in the south-east where that group succeeds the Ardrishaig Series.

'In the Loch Awe basin there is an immense epidiorite-sill of composite type, part of which is vesicular and corresponds petrologically to the pillow-lavas. I was for some time under the impression that the vesicular rock represents a contemporaneous lava; but the mapping of the area did not support this opinion, and pointed to its intrusive origin.

'Later, Mr. Kynaston mapped these rocks in the neighbourhood of Port Sonachan, and, after starting with a similar opinion, was forced to abandon it and considered that they represented an intrusion at a shallow depth beneath the surface.

'At a still later period Dr. Peach mapped similar rocks in the Loch Avich district, on the north-west side of Loch Awe, and, although inclined to regard them as lava-flows, could find no evidence in that direction, noting that no pyroclastic rocks had been found associated with them, and that their thickness and wide extension points rather to their intrusive nature.

'Rocks of this character have not been observed below the quartzite to the south-east, between the Loch Awe and the Ardrishaig Groups, but their intrusive nature may satisfactorily account for such absence.

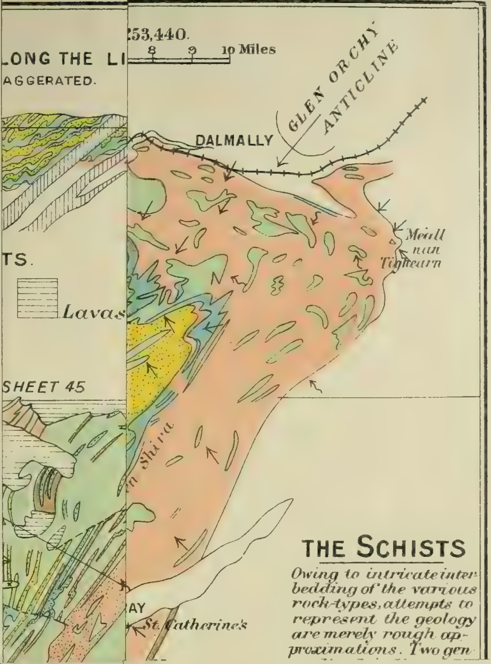
'Not only is there an absence of pyroclastic rocks in the Loch Awe basin, but the peculiar acid rocks associated with the pillow-lavas of Tayvallich are also unrepresented, and it is probable that the Tayvallich rocks occupy a higher horizon than those of the Loch Awe basin.'

Mr. BARROW congratulated the Author on the able manner in which he had dealt with the additional evidence afforded by the volcanic zone on the question of the succession in the Highland Rocks. He wished that the Author had gone more fully into the history of the question as a whole. The quartzite was believed by the speaker to be the Highland Quartzite, which crossed Scotland from Port Soy to Islay, and, as Harkness had shown,

R. Lunn photo.

PILLOW-LAVA, AN AIRD, Western Coast of Tayvallich Peninsula.

[Reproduced, by permission of the Controller of H.M. Stationery Office, from Mem. Geol. Surv. Scot. 1911 : 'Geology of Knapdale, &c.' pl. iii, facing p. 59.]



:53,440.
8 9 10 Miles
LONG THE LI
AGGERATED.
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GLEN ORCHY
ANTICLINE
DALMALLY
Meall
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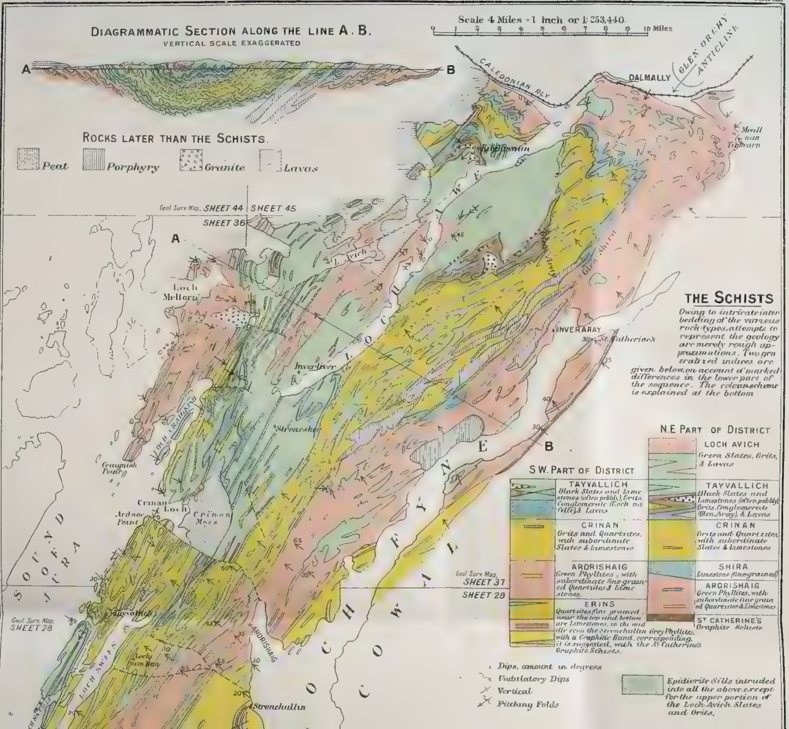
n Shira
AY
St. Catherine's
THE SCHISTS
Owing to intricate interbedding of the various rock-types, attempts to represent the geology are merely rough approximations. Two gen



Diagrammatic Section along the line A. B.
Vertical scale exaggerated
A
B
Scale 4 Miles = 1 Inch or 1: 253,440.
0 1 2 3 4 5 6 7 8 9 10 Miles
Rocks later than the Schists.
Peat
Porphyry
Granite
Lavas
Caledonian Rly
Dalmally
Glen Orchy Anticline
Meall nan Tighearn
Kilchrenan
Geol Surv Map. SHEET 44
SHEET 45
SHEET 36
L. Avich
Loch Melfort
Loch Awe
Inverliver
Inveraray
St Catherines
Loch Craignish
Stroneskar
Craignish Point
Crinan Loch
Ardnoe Point
Crinan Moss
Sound of Jura
Loch Fyne
Cowal
Geol. Surv. Map. SHEET 28
Geol Surv. Map. SHEET 37
SHEET 29
Tayvallich
Loch Sween
Ardrishaig
Stronchullin
THE SCHISTS
Owing to intricate inter bedding of the various rock-types, attempts to represent the geology are merely rough approximations. Two generalized indices are given below, on account of marked differences in the lower part of the sequence. The colour-scheme is explained at the bottom
N.E Part of District
LOCH AVICH
Green Slates, Grits, & Lavas
TAYVALLICH
Black Slates and Limestones (often pebbly) Grits, Conglomerate (Glen Aray), & Lavas
CRINAN
Grits and Quartzites with subordinate Slates & Limestones
SHIRA
Limestone (fine grained)
ARDRISHAIG
Green Phyllites, with subordinate fine grained Quartzites & Limestones
ST CATHERINE'S
Graphite Schists
S.W. Part of District
TAYVALLICH
Black Slates and Limestones (often pebbly), Grits, Conglomerate (Loch na Cille), & Lavas
CRINAN
Grits and Quartzites, with subordinate Slates & Limestones
ARDRISHAIG
Green Phyllites, with subordinate fine-grained Quartzites & Limestones.
ERINS
Quartzites fine grained, near the top and bottom are Limestones, in the middle come the Stronchullin Grey Phyllites, with a Graphitic Band, corresponding, it is suggested, with the St Catherine's Graphite Schists.
Dips, amount in degrees
Undulatory Dips
Vertical
Pitching Folds
Epidiorite Sills intruded into all the above except for the upper portion of the Loch Avich Slates and Grits.

reappeared in Ireland. The relative positions of the rocks of the groups had been proved by the speaker more than twenty years ago, and the conclusions reached were published in Sir Archibald Geikie's first Presidential address to the Geological Society (1891). The Blair Atholl Limestone (believed by the speaker to be the Tayvallich Limestone) was shown to be on one side of the Quartzite, and the Caenlochan Schist (Ardrishaig Phyllite) on the other. At the extreme north-eastern end of this outcrop, the quartzite was very thin, and passed down insensibly into the underlying dark schist, which there intervened between it and the Caenlochan Schist. Proceeding south-westwards, one noticed first the occurrence of small grains of the dark material at the base of the quartzite, later on small pellets, and finally in the area in question the original dark mud was at times completely eroded away; but now pellets of it, of larger size, occur in the quartzite. The real evidence adduced by the speaker, on which the succession turned, had never been published.

The AUTHOR, in reply, pointed out that Mr. Hill treated the mass of epidiorite in the vicinity of Loch Awe as a unit—either an immense sill or an immense lava. On this hypothesis Mr. Hill had, of necessity, set aside any interpretation involving the occurrence of lava, since parts of the mass showed definitely intrusive relations. The Author's observations led him to regard the mass as a complex series of lavas and associated sills.

Replying to Mr. Barrow, the Author drew attention to a paragraph written conjointly by Dr. Peach and himself in the Geological Survey Memoir on Sheet 28 (Scotland). The paragraph followed upon a description of the succession in the Tayvallich peninsula, and ran as follows [18, p. 61]:—

> 'It would be unnecessary to go beyond this, were it not that the relations of the Loch Awe Group in Argyllshire have been used in support of the theory of the "unconformable quartzite" in Perthshire and elsewhere. The writers are now of opinion that the change of front in the Tayvallich district strengthens, by analogy, the alternative interpretation of the Perthshire sections, which has for years been identified with the name of Mr. Barrow.'

Since the above was written the Author had tried to reach greater certainty in the matter, but without success. The district lying between Loch Awe and that part of Perthshire in which Mr. Barrow had worked was very difficult indeed to interpret. Quite apart, however, from the doubtful analogy between Loch Awe and Eastern Perthshire, the Author, speaking without any special knowledge, believed that Mr. Barrow was right in regarding the Perthshire quartzite as an interstratified member of the Perthshire sequence, and not an unconformable later group for ever making its appearance in isoclinal synclines.

Mr. Barrow had also referred to Islay. Here the Author was on familiar ground; and, while admitting certain general resemblances between the Islay-Jura sequence and that of Loch Awe, he found the differences of detail so considerable that he preferred to maintain an agnostic attitude in regard to matters of correlation.

16. *On* Two Deep Borings *at* Calvert Station (North Buckinghamshire) *and on the* Palæozoic Floor north *of the* Thames.

By Arthur Morley Davies, A.R.C.S., D.Sc., F.G.S., and John Pringle, of H.M. Geological Survey. (Read February 5th, 1913.)

[Plates XXXIII & XXXIV.]

Contents.

I. Introduction. [A. M. D.]

Calvert Station is situated on the main line of the Great Central Railway, 49 miles by rail from London (Marylebone Station) by way of Aylesbury, and about 11 miles north-west of the latter town. 'Calvert' is not the name of any village or hamlet, but the station was so named in memory of a former distinguished resident in the neighbourhood, General Sir Harry Calvert. It will not be found, therefore, on any map issued prior to the opening of the railway; and, for the benefit of any observers who may seek to locate the borings about to be described upon the only published geological map of the district (the original 1-inch sheet, 45 S.E.), it may be stated that the station lies in the south-eastern angle of the T-shaped road-junction, about an eighth of an inch north of the second 'n' in 'Charndon Lodge.' The road—really a green lane—which forms the stem of the T constitutes the boundary between the parishes of Charndon on the west and Steeple Claydon on the east. One of the borings is in the former parish, one in the latter.

Shortly after the opening of the railway in 1898, the late Mr. Itter, of Peterborough, opened a branch of his brickworks on the Charndon side of the green lane, and very extensive excavations have been made in the shaly clays of the *ornatum* zone. In 1905 a boring for water (hereinafter referred to as the Western Boring) was made in the brickfield; but only salt water was obtained, and at a depth of 380 feet inflammable gas was met with and has been coming off ever since. At 445 feet 8 inches the boring was abandoned. No use was made of the gas, and six years passed before its existence came to public knowledge, when, in 1911, the Guildhall Syndicate was formed to make further investigations. They set to work to clear out the Western Boring and carry it deeper down, and at the same time started a new boring (which we call

the Eastern Boring), beginning with cores 18 inches in diameter, with the view of reaching a depth of 2000 feet if necessary. The actual depth reached was about 1398 feet, in April 1912. The old boring was restarted, with cores 2 inches in diameter, at 446 feet and continued to 649 feet by November 28th, 1911, when it was stopped.

We are very greatly indebted to Mr. A. Hiorns Jr., resident engineer to the Guildhall Syndicate, for allowing us opportunities to examine and take samples of the cores; for the readiness with which he has given us information on matters that we could not investigate personally; and for having carried on the Eastern Boring, in the hope of adding to geological knowledge, after the prospect of economic success was at an end.

During the progress of the boring, one of us paid seven visits, at intervals between September 1911 and April 1912; but some of these visits were limited to so short a time, that the examination of the cores was much less thorough than was desirable. Meanwhile the other author, accompanied by Mr. J. M. Muir, proceeded to Calvert in December and January, to examine and collect from the cores for the Geological Survey. The two series of observations and collections were thus to some extent supplementary; but, owing to the confidential nature of the information, no comparison of the results was possible until after the former author had completed a paper and presented it to the Society. At the suggestion of the President (Dr. Strahan) he then examined the material collected by the Survey, and discussed the correlation of the strata with the second author. As a result some modifications in the interpretation became necessary; but, as the key to part of the Jurassic sequence lay in certain unpublished information obtained by the Geological Survey during the excavation of the Fritwell railway-cutting, it was seen that only by a joint paper could the boring be adequately dealt with. Hence the present communication. The parts that are the work of either author exclusively (or almost so) are indicated by his initials.

While each of us is generally responsible for the identification of fossils in the sections which he has initialled, acknowledgment of kind assistance must be made to Mr. S. S. Buckman (who identified all the ammonites and several of the brachiopods), to Dr. Kitchin, Dr. Matley, and Mrs. Shakespear. We must also acknowledge the help in the correlation of the Oolites derived from the papers of Mr. E. A. Walford and Mr. L. Richardson, to which one of us must add his thanks to the former gentleman for personal exposition of the Sharp's Hill section. The photomicrographs were taken in the Research Laboratory of the Imperial College of Science & Technology by Mr. H. G. Smith, B.Sc., to whom we are much indebted. To Prof. T. T. Groom one of us is indebted for the loan of Malvern specimens, for comparison with the sills passed through in the boring.

A selection of cores has been secured for the Museum of the Buckinghamshire Archæological Society, at Aylesbury.

II. Description of the Borings.

(1) The Eastern Boring.—General Remarks. [J. P.]

The site of the Eastern Boring is in a field in Steeple Claydon parish, numbered 15 on Sheet XXII–2 of the $\frac{1}{2500}$ Ordnance map (Buckinghamshire) dated 1899, at a point immediately north of the words 'Cattle Pens' on that sheet. The height above Ordnance datum may be estimated as 290 feet, by reference to the nearest indicated altitudes on the adjacent roads.

Details of the Strata passed through in the Eastern Boring.

		Thickness in feet	Thickness inches.	Depth in feet	Depth inches.
	Surface-soil	4	0	4	0
Oxford Clay. *ornatum* zone.	Dark-blue and grey clays with occasional nodules: the basement-bed is a tough, brownish, shelly clay full of fragments of *Cosmoceras*, *Belemnites*, *Gryphæa*, etc.	93	3	97	3
	Non-sequence.[1]				
Forest Marble.	Bluish-grey and grey limestone, oolitic in places, and becoming earthy below: unfossiliferous	1	9		
	Dark-grey earthy limestone		9		
	Hard grey limestone, shelly in places, fragments of *Ostrea* abundant; base of bed yellowish and somewhat sandy	2	0		
	No core seen for	5	6		
	Grey earthy limestone, with plant-fragments and *Gervillia*	1	3		
	Bright bluish-green clay		3		
	Grey earthy limestone	2	0		
	Irregularly thin-bedded bluish-grey limestone, oolitic and shelly in places	1	6		
	Dark-grey earthy limestone on paler grey blotchy limestone, oolitic in places.	7	0		
	Grey marly clays, passing down into brown and greenish clays, with a bed of green sandstone and a hard band of grey limestone. Lignite plentiful	16	9	136	0
		38	9		
	Non-sequence.				
	Very compact, blotchy, grey limestone (possibly equivalent to 'cream-cheese' top)	1	6		
	Yellowish marly limestone, shelly in places	2	0		
	Grey marly limestone, full of dark grains: limestone becoming darker below	6	0		
	Grey blotchy limestone yielding *Terebratula bathonica*	2	6		
	Grey marl		6		

[1] The term 'non-sequential' was proposed by Mr. S. S. Buckman, to denote the relationship of strata 'when the sequence is incomplete, but the planes of the deposits are practically parallel' Q. J. G. S. vol. li (1895) pp. 390–91.

		Thickness in feet	*inches.*	*Depth in feet*	*inches.*
GREAT OOLITE SERIES.	Dark marly clay, full of *Ostrea sowerbyi* M. & L. and *Rhynchonella* sp. [of the '*concinna*' type]	2	6		
	Grey limestone, somewhat earthy: unfossiliferous	5	0		
	Dark-grey marl: *Pholadomya* cf. *deltoidea* abundant		6		
	No core seen between 156 feet 6 inches and 181 feet 9 inches. Beds described on the borer's record as soft, dark-grey, sandy shales	25	3		
	Dark-grey shaly limestone	1	0		
	Grey limestone with *Ostrea* sp.	4	0		
	Dark marly band		6		
	Grey limestone	1	0		
	Grey marly clay with a thin band of limestone; clay very fossiliferous. *Rhynchonellæ* of the '*concinna*' type and *Ostrea sowerbyi* M. & L. occur in great abundance	2	0		
	Grey limestone, with an *Ostrea* band near the top	3	6		
	Dark-grey marl		3		
	Grey thinly-bedded limestone, with lignite-fragments	1	6	195	6
		59	6		
	Non-sequence.				
CHIPPING-NORTON LIMESTONE.	Yellowish oolitic limestone	2	0		
	Sandy limestone, with abundant oolitic grains	5	0		
	Yellowish oolitic limestone, false-bedded		6		
		7	6	203	0
	Non-sequence.				
DOMERIAN—*algovianum* zone.	Shales, well-laminated, varying in colour from grey to brown [*Amaltheus* sp. probably from this horizon], *Nuculana* sp. Thickness doubtful, owing to displacement of part of the cores, but estimated at	8	0	211	0
	Fine loamy sand [not seen]	3	0	214	0
CHARMOUTHIAN—*capricornus* to *jamesoni* zones.	Shales, well-laminated, sometimes jointy, varying in colour from greenish-grey to brown: septaria in places, a large one at 237 feet. *Nuculana* sp.; a capricorn ammonite at about 300 feet ......about	140	0	354	0
	Fossiliferous limestone, with capricorn ammonites and lamellibranchs	2	6	356	6
	Grey shale [cores not seen]	73	6	430	0
	Pale-grey shales, less fissile than those above; with linear aggregates of pyrite; *Orbiculoidea* aff. *holdeni* (Tate)	8	0	438	0
	Tough grey limestone, ironshot at the top, with many large angular and smaller rounded fragments of grey shale, sandstone, etc.; very fossiliferous: *Zeilleria waterhousei* (Davidson) and other brachiopods, some lamellibranchs, and a derived fragment of *Echioceras microdiscus* (Quenstedt)	2	6	440	6
	Dark clay	3	0	443	6
		240	6		

	Unconformity.	Thickness in feet	inches.	Depth in feet	inches.
Lower Tremadocian. Shineton Shales. Estimated true thickness = about 480 feet.	Soft greenish-grey shales, red-stained in places, particularly on the joint-faces. Dip varying from 65° to 70° ..	36	6	480	0
	Soft dark-red and green micaceous shales: fragments of *Clonograptus (?)* at 490 feet	13	6	493	6
	Soft greenish-grey shales, passing downwards into grey shales: *Clonograptus* at 496 feet	2	6	496	0
	Jointed grey micaceous shale, with two sills of olivine-basalt at 570–572 feet and 606–608 feet. *Clonograptus* and *Obolella* abundant at 498, 517, and 530 feet. Between 481 and 500 feet the shales dip steadily at an angle between 65° and 70°; at 555 feet the dip decreased to 49°: *Clonograptus, Obolella.* About 600 feet, abundant *Clonograptus* and *Obolella.* At 635 feet, dip=44°: *Clonograptus.* At 740–742 feet, graptolites and *Obolella.* At 783 feet, dip=49°. At about 845 feet, dip=40°, rising locally to 80°: *Clonograptus.* At 961 feet, worm-castings. At 1135 feet, dip=51°. At about 1165 feet, dip=48°: abundant fragments of graptolites. From 1180 to 1220 feet, the beds are almost vertical. At 1280 feet, dip=59°. At 1398 feet, harder rock touched, no cores drawn (igneous sill?)	902	0	1398	0
	Total apparent thickness	954	6		

(a) Jurassic Rocks.—(i) Oxford Clay. [J. P.]

Owing to the state of the cores, it was impossible to secure exact details of the Oxford Clay passed through in the Eastern Borehole. The information obtained from the borer's journal, however, shows that grey and blue clays, some of which were hard and tough, were met with to the depth of 95 feet. Below this point was a hard, tough, brownish clay, full of broken shell-fragments and some lignite; and from this portion of the core the following fossils were obtained:—

Lignite.
Gryphæa bilobata J. de C. Sow.
Belemnites oweni Pratt.
Cosmoceras sedgwicki (Pratt).
Cosmoceras stutchburyi ? (Pratt).

In Messrs. Itter's brickyard—the site of the Western Borehole—a fine section is obtained of nearly all the beds passed through in the Eastern Boring, and from this locality Dr. Davies & Mr. E. Neaverson, B.Sc., of Aylesbury, collected, among other forms, *Cosmoceras elizabethæ* (Pratt) and *C. jason* (Reinecke). From these forms, and from the evidence furnished by the lowest bed of Oxford

Clay in the borehole, it can be safely assumed that all beds passed through at Calvert, to the depth of 97 feet 3 inches, belong to the *ornatum* zone.[1]

(ii) Forest Marble. [J. P.]

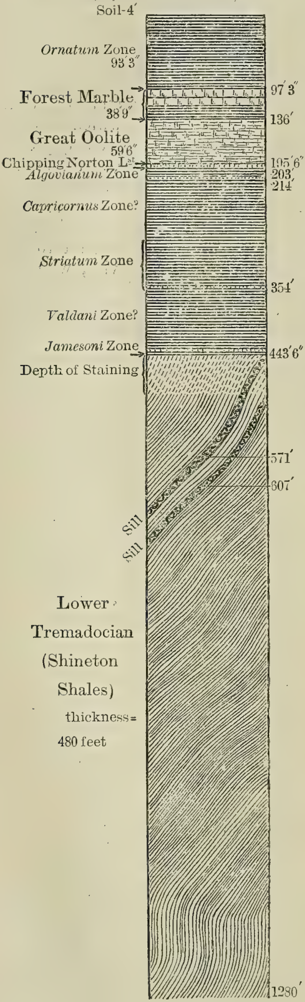
The Oxford Clay rests upon a grey, partly oolitic, and somewhat earthy limestone; but, unfortunately, no specimen which showed the nature of the junction was obtained. The tough shelly clay with *Cosmoceras* (described above) occurred, however, at the actual base of the *ornatum* beds in the borehole, and no trace of any conglomerate was found. The limestone on which the clay reposed was unfossiliferous, and its inclusion in the Forest Marble is made on lithological grounds. In appearance the bed is similar to the limestones associated with the green clay. Dr. Davies, who examined this and other limestones under the microscope, gives details of its structure on p. 318. It is oolitic, and is thus quite unlike any of the beds of the Cornbrash; moreover, it passed gradually downwards into limestones which contained Forest-Marble fossils, so that there can be no doubt that it is correctly included in that formation. Thus there is a marked non-sequence, both the Kellaways Rock and the Cornbrash being absent.

The details of the Forest Marble at Calvert show that the upper portion of the group is more calcareous than the lower, and in this respect they agree with the descriptions of the various sections of the formation exposed in the Bicester neighbourhood. The limestones in the core differ considerably in texture and purity: some beds are bluish grey, oolitic, and shelly; while others are softer, darker, and earthy, and frequently contain irregularly-shaped lumps of pale-grey clay. It was noticed also that many tube-like hollows, each filled with a marly and markedly-oolitic clay, traverse the beds of some of the more clayey limestones. The lower portion of the group is chiefly composed of grey, brown, and greenish clays, with a bed of greenish sandstone. Unfortunately, the cores were badly obscured at this point, and the details were somewhat difficult to secure, but those given on p. 310 probably represent the correct order of their succession. The occurrence of green or greenish clays in the Forest Marble is characteristic. They are met with in all the sections of the formation that are exposed in the railway-cuttings between Blackthorn Hill and Ardley Wood, near Bicester,

[1] [The term '*ornatum* zone' is here used in its wide sense: at least two horizons can be distinguished within it in England—a higher *duncani* zone with pyritized ammonites, seen at Summertown (Oxford) and many places in the Peterborough district; and a lower zone with crushed ammonites, known at Christian Malford, and Dogsthorpe (Peterborough). It is the latter zone which is found at Calvert: it is usually termed the *jason* zone, but this is an unsatisfactory name, as the identity of the index-species is uncertain. Between these two zones in France and South Germany lies the *castor* and *pollux* zone, with a fauna unknown in England. See L. Reuter, 'Die Ausbildung des Oberen Braunen Jura im Nördlichen Teile der Fränkischen Alb' Munich, 1908, pp. 75–81.]

Fig. 1.—*Vertical section of the Eastern Boring.*

[The arrows indicate non-sequences.]



and they have been noted in the shafts at Dover and in the cores of the Brabourne borehole.[1]

A critical comparison of the Forest Marble passed through at Calvert, with the sections exposed in the new railway-cuttings near Bicester, shows some interesting points both of resemblance and of difference. The formation in the Calvert borehole is considerably thicker than any of the sections where the whole of the beds have been cut through in the Bicester cuttings. At Blackthorn Hill the Forest Marble is only 21 feet 9 inches thick[2]; in the cuttings between Bucknell and Ardley Wood the details show the formation to be slightly thinner.[3] At Calvert the beds reach the total of 38 feet 9 inches, and are thus very nearly twice as thick.

In the borehole, however, the thickening appears to have taken place in the clays. In the section at Blackthorn Hill[4] there is a bright bluish-green clay to which Mr. Barrow drew special attention, and he remarked that its presence could scarcely be missed even in a hand-boring. A clay indistinguishable from the Blackthorn-Hill bed was passed through at Calvert. It thus appears to mark a

[1] G. W. Lamplugh & F. L. Kitchin, 'On the Mesozoic Rocks in some of the Coal-Explorations in Kent' Mem. Geol. Surv. 1911, pp. 28 & 48.

[2] G. Barrow, 'The New Great Western Railway from Ashendon to Aynho, near Banbury' Summary of Progress for 1907, Mem. Geol. Surv. 1908, p. 145.

[3] *Ibid.* p. 149. [4] *Ibid.* p. 145.

well-defined horizon. Taking this bed of green clay as a datum, we found that in the borehole there is 14 feet 9 inches of grey earthy and oolitic limestones between it and the Oxford Clay; while at Blackthorn Hill a thickness of 18 feet 3 inches is recorded between it and the base of the Cornbrash: thus there is a remarkably close agreement. Below the green clay at the latter locality, however, the clays are only a little more than 3 feet thick, whereas in the cores at Calvert 27 feet of clays are recorded. Even allowing for all possible chances of error, by excluding the limestones below the green band from the measurements, there still remains a considerably greater thickness of clay.

Excepting the highest bands of limestone, the Forest Marble is fairly fossiliferous throughout; but, as a rule, the forms are poorly preserved. Some of the limestones are shelly, *Ostrea* appearing to be plentiful in some beds; but the fossils were difficult to extract, owing to the hardness of the limestone. In the grey earthy limestones overlying the band of green clay *Pteroperna costatula* (Desl.) was abundant. The basal clays contained a considerable quantity of lignite. The following is a list of the fossils obtained between the depths of 97 feet 3 inches and 136 feet:—

Lignite.
Acrosalenia hemicidaroides Wright.
Serpula sp.
Astarte sp.
Gervillia crassicosta Morris & Lycett.
Modiola imbricata J. Sow.
Modiola sp.
Nucula (?).
Ostrea sp.
Pecten (Camptonectes) annulatus (?) J. de C. Sow.
Perna sp.
Pholadomya sp.
Pseudotrapezium (?) caudatum (Lycett).
Pteroperna costatula (Desl.).
Trigonia moretoni Lycett.
Trigonia pullus (?) J. de C. Sow.
Trigonia cf. *scarburgensis* Lycett.
Nerinæa sp.
Nerinella funiculus (Desl.).
Nerinella sp.
Pleurotomaria (?).
Crustacean remains.
Fish-fragments.

(iii) Great Oolite Series. [J. P.]

Beneath the clays of the Forest Marble the cores showed a series of marly limestones passing downwards (according to the borer's record) through a thick band of dark grey sandy shales into marly clays and limestones. The lowest bed is a thinly-bedded limestone with lignite. Dr. Davies has described the microscopic structure of a number of the limestones on p. 318, so that few further observations need be added to his descriptions. Nearly all the beds are dark grey, and this coloration is due to the presence of numerous minute black fragments of limestone which are very abundant in some of the clays.

The uppermost bed of the section immediately underlying the greenish clays of the Forest Marble is a compact, blotchy, grey limestone; and, although it differs somewhat in colour from the 'Cream-Cheese' top of the Great Oolite exposed in the Bicester cuttings, it possesses so many of the characters of that bed that its relationship was easily recognized. Dr. Davies's observations

on the microscopic structure and included organic remains of the Calvert rock confirm its correlation with the Bicester bed. The upper surface of the limestone is irregular and piped, and the overlying clays extending downwards into the pipes present an uneven junction. Similar irregularities of surface of the 'Cream-Cheese' top were noticed in the Bicester cuttings, and they are doubtless the results of contemporaneous weathering. The sudden passage upwards of a fairly pure limestone into clays with lignite denotes a considerable change of level in the area of deposition; and the fact that at Calvert root-like processes were seen to extend down from the overlying Forest-Marble clays into the infilled hollows of the limestone, suggests that for some time the 'Cream-Cheese' top was a land-surface.[1] There is at Calvert, therefore, as well as in the Bicester cuttings, a non-sequence between the two groups.

Underlying the highest member of the Great Oolite is a yellowish marly limestone, 2 feet thick. It is the only bed that possesses the characteristic colour of the Great Oolite limestones exposed in the railway-cuttings between Bucknell and Ardley Wood. Unfortunately, the cores of the sandy shales were not preserved at the boring, and so no comparison is possible; it is probable, however, that they represent the Stonesfield Slate. The remainder of the section consists of grey marly clays and limestones, which agree closely in character with the lower beds of the Great Oolite exposed in the long railway-cutting between Ardley Wood and Fritwell Tunnel, the details of which are not yet published.

The limestones and clays of the Great Oolite at Calvert are, generally, fossiliferous; but the fossils, like those of the Forest Marble, are badly preserved, the majority of them occurring in the form of casts. The most abundant forms are *Rhynchonella* and *Ostrea*; a horizon between the depths of 188 feet 3 inches and 193 feet 9 inches yielded hundreds of specimens. This band is clearly comparable with the marls overlying the Neæran Beds in Sharp's-Hill Quarry.[2] In the present state of knowledge no attempt has been made to give a definite name to the species to which the *Rhynchonellæ* belong, but the type with which the forms appear most closely allied is named in the appended list. Regarding the other fossils which were collected little need be said, since most of them are characteristic of the Great Oolite. The *Ostrea* which is recorded in the list as *Ostrea* sp. nov.(?) is apparently an undescribed form, and still remains to be identified. Many specimens of *Pholadomya* cf. *deltoidea* (J. Sow.) were obtained at the depth of 156 feet, and they are similar to the *Ph. deltoidea* collected by Mr. J. Rhodes and Mr. H. B. Woodward from the Fuller's-Earth

[1] [On clearing the surface of the Great Oolite, after the removal of the core to the Aylesbury Museum, I found that the surface was very irregular, the dark patches in the limestone having weathered out into rounded prominences, almost certainly the result of subaërial weathering.—*A. M. D.*]

[2] L. Richardson, 'The Inferior Oolite & Contiguous Deposits of the Chipping-Norton District' Proc. Cotteswold Nat. F. C. vol. xvii, pt. 2 (1911) p. 207; also E. A. Walford, 'On some New Oolitic Strata in North Oxfordshire' Buckingham, 1906, p. 8.

Rock of Thornford and Milborne Port.[1] The type described by Sowerby came from the Oxford Clay of Peterborough, but the form shown in his figure does not appear to differ from the forms found in the Great Oolite.

The following is a list of the fossils obtained from the cores between 136 and 195 feet:—

Lignite.
Sponge-spicules.
Bryozoon (?).
Rhynchonella sp. [of '*concinna*' type].
Rhynchonella sp. [of '*obsoleta*' type].
Terebratula bathonica S. S. Buckman.
Terebratula globata auctt.
Terebratula sp.
Astarte (?).
Cyprina (?).
Grammatodon hirsonensis (d'Arch.).
Gresslya peregrina (Phill.).
Homomya gibbosa (J. Sow.).
Modiola imbricata J. Sow.
Modiola sp.
Ostrea sowerbyi Morris & Lycett.
Ostrea sp. nov. (?).
Pecten (Camptonectes) annulatus (?) J. de C. Sow.
Cf. *Pecten (Camptonectes) lens* J. Sow.
Pholadomya cf. *deltoidea* (J. Sow.).
Pholadomya heraulti Ag.
Pholadomya sp.
Pleuromya sp.
Pseudotrapezium (?) caudatum (Lyc.).
Pteroperna costatula ? (Desl.).
Tancredia (?).
Trigonia cf. *pullus* J. de C. Sow.
Unicardium impressum Morris & Lycett.
Unicardium cf. *parvulum* Morris & Lycett.
Natica cf. *zelima* d'Orb.

(iv) Chipping-Norton Limestone. [J. P.]

Underlying the thinly-bedded limestone at the base of the Great Oolite at Calvert is a yellowish oolitic limestone, which passes below into a sandy limestone with many oolitic grains. The lowest bed is false-bedded, and rests on the shales of the *algovianum* zone. By their characters the limestones were recognized as representing the Chipping-Norton Limestone. Unfortunately, however, they proved but sparingly fossiliferous, and so their correlation is based entirely on lithology. Dr. Davies had sections made of several specimens; and, as a result of his examination of their microscopic structure, he states that they are identical with Bed 22 of Mr. E. A. Walford in Sharp's-Hill Quarry.[2] Since there was no trace of the Neæran Beds in the cores, there is thus a marked non-sequence at the base of the Great Oolite. In the section at Sharp's Hill the beds between the *Rhynchonella-Ostrea* band and Bed 22 of Mr. Walford's succession reach the thickness of about 20 feet 7 inches (*loc. cit.*). At Calvert there is about 5 feet of marls and limestones between the same horizons; therefore, the thickness of beds unrepresented between the Great Oolite and the Chipping-Norton Limestone is nearly 16 feet.

The following fossils were found in the sandy limestones; the brachiopods, however, were too fragmentary for identification. All the specimens are in the collection of Dr. A. M. Davies.

Rhynchonella sp.
Terebratula sp.
Ostrea sowerbyi Morris & Lycett.
Ostrea aff. *acuminata* J. Sow.

[1] H. B. Woodward, 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iv (1894) p. 237.

[2] 'On some New Oolitic Strata in North Oxfordshire' Buckingham, 1906, p. 10.

(v) Microscopic Structure of the Great Oolite Series. [A. M. D.]

Limestone at 98 feet.—This, the topmost bed of the Forest Marble, is somewhat oolitic, the grains having large nuclei with a rather thin coating; fragments of shells, often waterworn, abound, including echinodermal, bryozoan, brachiopod, and gastropod fragments; and there are also seen under the microscope what appear to be waterworn fragments (up to 1 mm. by 0·3 mm.) of a limestone of the same structure as the crystalline matrix in which they are embedded.

Limestone at 119 feet.—This shows an extremely fine-grained calcite-matrix, in which are set (*a*) a very few quartz-grains, measuring about ·05 mm. in diameter; (*b*) more frequent grains of clear calcite, of about the same size; (*c*) abundant waterworn calcareous fragments with a dusky appearance, also of the same size or a little larger (up to 0·1 mm.), including some foraminifera and echinoderm-fragments.

A limestone at 123 feet is very similar.

The top bed of the Great Oolite (at 136 feet) has a very finely-crystalline calcite-matrix, with foraminifera, echinoderm-fragments, shell-fragments, and rolled minute grains of dusky calcite. There are a few tubular rod-like bodies, which may be sponge-spicules. These, however, are so scarce that they would have been overlooked if they had not been specially searched for, on account of their abundance in the 'Cream-Cheese' bed of the Bicester railway-cutting, with which the bed now described is correlated. The two beds are of generally similar structure, but the fragments embedded in the matrix are decidedly smaller in the 'Cream-Cheese' bed.

Great Oolite limestones at 143, 144, 146, 155, 191, and 195 feet.—While varying much in coarseness of grain and proportion of matrix to fragments, these show certain features in common. They are composed largely of organic fragments—of echinoderms, brachiopods, and lamellibranchs—with occasional oolite-grains and many rolled fragments of limestone, conspicuous by their duskiness, varying from 0·2 mm. up to 1 mm. in diameter. In several cases, fragments of oolitic limestone occur, a fact which suggests that many of the isolated oolite-grains may be derived. In some beds, subangular quartz-grains are abundant (=about 0·1 mm. in diameter). The bottom bed of the Great Oolite (at 195 feet) shows scattered oolite-grains and fragments of oolitic limestone, all with the dusky margin which appears to denote derivation (Pl. XXXIII, fig. 1).

Thus, throughout the whole of the Forest Marble and Great Oolite we find constant evidence that, while the limestones were being deposited, other limestones of very similar character and

oolitic limestones also were undergoing denudation at no great distance. This fits in well with the repeated non-sequences of which the stratigraphy gives evidence.

Oolitic limestone at 197 and 203 feet (Chipping-Norton Limestone).—These are quite typical oolitic limestones, the only ones in regard to which it can be confidently asserted that the majority of the grains are of contemporaneous origin. The two beds are separated by very sandy limestones, in which, however, there are also abundant oolite-grains.

Even these beautifully oolitic rocks give the same indications of the destruction of pre-existing oolitic limestones as those that we have seen in the overlying strata. Thus not only do we find occasional fragments of oolitic limestone in which several broken oolite-grains are still united by the calcite-matrix, but we even find worn oolite-grains serving as nuclei to new oolite-grains [1] (Pl. XXXIII, fig. 2).

Another curious appearance seen in these oolitic rocks under the microscope is the indentation of the margins of oolite-grains, usually by angular sand-grains, but sometimes by other oolite-grains or by shell-fragments (Pl. XXXIII, fig. 3). It is not easy to frame an explanation of such a structure. The only other rock in which I have detected the same appearance is the Chipping-Norton Limestone (Bed 22 of Mr. Walford's succession) of Sharp's Hill. That limestone has much more abundant quartz-grains, also its oolite-grains are rather smaller and have sand-grains much more frequently for their nuclei; but these are differences of degree, rather than of kind. The general appearance of the two rocks is similar, and worn fragments of oolitic limestone occur in both.

(vi) Lias: Domerian [2] and Charmouthian. [A. M. D.]

The change from the variable beds already described to the markedly-uniform Liassic shales was very striking. The writer of this section fortunately saw the greater part of the uppermost 100 feet of Lias cores soon after they were brought up, at the end of October 1911: for, being unprotected from the weather, they were soon reduced to mud. The finding of a capricorn ammonite at

[1] [It was suggested by Dr. Matley during the discussion that these derived fragments of oolitic limestone might be of practically contemporaneous origin, being broken-up as soon as formed. This may be so in the last-mentioned case (worn oolite-grains as nuclei to new grains), but I do not think that the explanation can apply to the majority of cases.—*A. M. D.*]

[2] As it is desirable, on several grounds, to be able to distinguish between the Middle Lias, in the restricted sense of the Geological Survey, and the underlying clays which are also included in the Middle Lias by many authors, I follow Mr. Buckman in restricting the name 'Charmouthian' to the latter and adopting for the former Dr. G. Bonarelli's term 'Domerian' (Rendiconti R. Ist. Lombard. ser. 2, vol. xxviii, 1895, pp. 326, 415). According to Dr. A. Bettoni, the term should properly be 'Domarian,' being derived from Monte Domaro, called Monte Domero by Bonarelli (Mém. Soc. Paléont. Suisse, vol. xxvii, 1900, No. 3, p. 3, footnote).

about 300 feet at once made clear the importance of the non-sequence between Oolites and Lias. Although no ammonite was then found at any higher level, the presence of the same *Nuculana* at intervals throughout these 100 feet of shale indicated that there could be no other break in the sequence, and suggested that no stage higher than Charmouthian was present. Long afterwards it was discovered that a section of core which had been placed near the Oxford-Clay cores, and had been taken for part of them, contained the same species of *Nuculana* as that already mentioned. Fragmentary ammonites which it also contained were at once submitted to Mr. Buckman, who identified them as belonging to the *algovianum* (lower *margaritatus*) zone. It became evident that the cores had been displaced, and doubt was thus thrown upon the record of depth at which other fossils had been collected. This doubt is of little consequence, except in regard to those recorded as coming from the depth of 210 feet: in that case it becomes uncertain whether they come from below, or from above, the horizon adopted as the boundary between Domerian and Charmouthian.

Except for three interruptions, the Lias from top to bottom, 240 feet in all, appears to consist of shales of very uniform character. Those near the base are distinctly less fissile than those towards the top, but otherwise the only differences noted are in colour; and it may be doubted whether these really exist to the extent recorded, for specimens which at the time of collecting were noted as brown have by drying become pale grey. Although few cores were seen between 300 and 430 feet, there is no reason to suppose that any great variation occurred between those depths. Septaria were met with at several levels.

The three interruptions already mentioned are a bed of sand, 3 feet thick, reported near the top, and two fossiliferous limestones (each some $2\frac{1}{2}$ feet thick), at about 354 and 440 feet respectively.

The evidence of the misplaced core proves the presence of the *algovianum* zone. It is probable that this came from immediately below the Chipping-Norton Limestone, because there is no evidence of any higher zone of Lias. In the absence of any other evidence it will be convenient to take the bed of sand at 211–214 feet as marking the base of the Domerian, which would then be represented by the topmost 11 feet only.

Of the zones of the Charmouthian, only two are clearly proved present—ammonites of the *striatum* zone were found at 300 and 354 feet, and brachiopods of the *jamesoni* zone at 438–440 feet. It is reasonable to assume that some part of the 86 feet from 214 to 300 belongs to the *capricornus* zone, and some part of the 84 feet between 354 and 438 to the *valdani* zone. The minimum thickness of the *striatum* zone is 55 feet (300 to 354 inclusive).

The fossiliferous limestone near the base (and with it, presumably, the underlying 3 feet of unfossiliferous clay) may safely be ascribed to the *jamesoni* zone, on the evidence of its brachiopod fauna. The most abundant form is *Zeilleria waterhousei* (Davidson), the specimens being in precise agreement with some from the *jamesoni*

zone of the Radstock district. *Terebratula radstockensis* and some of the species of *Rhynchonella* tabulated below are no less characteristic; and, although the *Spiriferina* comes nearest to one which is said to occur in the *striatum* zone of Cheltenham, and *Rh. rimosa-multiplicata* is placed by Mr. Buckman as *striatum-valdani*, the balance of evidence is decisive for the *jamesoni* zone.

But the most interesting discovery in this basement-bed was a derived fragment of *Echioceras microdiscus* (Quenstedt), a *raricostatum*-zone ammonite. That it is derived was shown by the following facts, determined during extraction:—(1) It is the internal cast of the body-chamber only, and as it lay in the rock there were portions of the shell adherent in some parts and not in others; (2) the matrix of the cast was not the same as that of the rock around; (3) it was standing vertically. We have here, then, conditions very similar to those known at various places near Radstock, where derived *raricostatum*-zone ammonites are found at the base of the *armatum* zone.

It is important to notice that the small thickness of Lias in this boring is due to the absence of many zones, not to the thinning of those that are present. The thickness of the zones represented is normal; indeed, it is if anything greater than might have been expected—greater than that of the same zones at Lyme Regis, for example.

List of Fossils from the Lias—Domerian and Charmouthian—*algovianum* to *jamesoni* zones.

[* In the collection of H.M. Geological Survey. † In the collection of Dr. A. M. Davies.]

From an unknown depth, probably between 203 and 210 feet (*algovianum* zone):—

†*Cristellaria* sp.
*†*Chlamys* sp. (immature, maximum length=5·5 mm., showing abrupt change from smooth to costate at 3·3 mm. from the umbo).
**Goniomya hybrida* (Münster), or *G. heteropleura* Agassiz.
†*Nucula cordata (?)* Goldfuss.
*†*Nuculana* cf. *quenstedti* (Tate).
**Amaltheus* sp. cf. *depressus* (Simpson) and *clevelandicus* (Young & Bird).

At 210 feet? (*algovianum* or *capricornus* zone?):—

†*Arca* or *Cucullæa* sp.
†*Goniomya hybrida* (Münster) or *G. heteropleura* (Agassiz).
†*Nuculana* cf. *quenstedti* (Tate).
†*Pseudomelania (?)* sp. (young).
†*Turbo* sp. (young).

At 230 feet (probably *capricornus* zone):—

†*Nucula cordata (?)* Goldfuss.
†*Nuculana* cf. *quenstedti* (Tate).

At about 300 feet (*striatum* zone):—

†*Isocrinus*, columnals.
†*Nuculana* cf. *quenstedti* (Tate).
†*Androgynoceras hybrida* (d'Orbigny), capricorn stage.
†*Belemnites*, phragmocone of a large species.

From fossiliferous limestone, 354 feet (*striatum* zone):—

**Cardinia attenuata* (Stutchbury).
**Ostrea* sp.
**Pecten disciformis* Schübler.
**Pseudopecten æquivalvis* (J. Sowerby).
**Plagiostoma* sp.
**Androgynoceras* cf. *intracapricornus* (Quenstedt)—allied to *A. hybrida* but less evolute, ornament not coarse enough for the *cheltense* series.
**A.* aff. *latæcosta* (J. de C. Sowerby).

At 431–432 feet (*valdani* or *jamesoni* zone):—

†*Orbiculoidea* aff. *holdeni* (Tate).
Ammonites, immature and unidentifiable.

From fossiliferous limestone, 438–440 feet 6 inches (*jamesoni* zone):—

**Rhynchonella* cf. *curviceps* (Quenstedt).
†*Rhynchonella rimosa* von Buch.
*†*Rhynchonella rimosa-multiplicata* (Quenstedt).
†*Rhynchonella variabilis* (as figured by Davidson).
**Terebratula radstockensis* Davidson.
*†*Zeilleria waterhousei* (Davidson).
*†*Zeilleria* aff. *waterhousei* (Davidson).
†*Spiriferina* aff. *punctata* (J. Buckman).
**Pecten disciformis* Schübler.
**Pseudopecten æquivalvis* (J. Sowerby).
**Plagiostoma* cf. *gigantea* J. Sowerby.
Fragments of other lamellibranchs.
†*Discohelix aratus* (Tate).
†*Trochus* sp.
†*Echioceras microdiscus* (Quenstedt), derived.
†*Belemnites* sp.
†Reptilian bone, fragments.

(*b*) Palæozoic Rocks.—(i) Tremadoc Shales. [J. P. & A. M. D.]

Unfortunately, when the boring entered the Palæozoic rocks it was found that the soft dark clay of the Lower Lias and the greenish-grey shales of the Tremadoc had got mixed. By carefully cutting the core, however, one of us secured a small specimen which clearly shows the relationship between the two formations; but, apart from this evidence, the dips obtained at a short distance below the junction strikingly demonstrate the existence of a marked unconformity, and prove beyond any doubt that the low-dipping Jurassic clay rests on the upturned edges of highly-inclined Tremadoc Shales. No pebbles were found in the basement-bed; but, as has already been noted (p. 311), the limestone overlying the clay contains fragments of the older rocks, so that the erosion of the Palæozoic floor outside the Calvert area must have continued for some time during the deposition of the lowest beds of the Lias.

The highest beds of the Tremadoc between the depths of 443 feet 6 inches and 496 feet present a wholly different appearance when compared with the lower beds; and, when the core was brought to the surface, it was thought that Coal Measures had been encountered, until the discovery of a graptolite-fragment (*Clonograptus ?*) placed the age of the beds beyond doubt. The uppermost $36\frac{1}{2}$ feet are soft, greenish-grey, slightly-micaceous shales. In the core they were distinctly green in hue; but, on drying, the colour has become greenish grey. On several horizons, particularly near

the depth of 480 feet, the shales are traversed by small joints, the walls of which are stained a bright red. In some beds where no joints are discernible, narrow dull red bands are to be seen on the bedding-planes; and these, together with blotches of a similar colour, give a mottled appearance to the shales.

Below this point for a distance of 13 feet the core showed a series of soft dark-red and green beds, which at the depth of 490 feet yielded a fragment of *Clonograptus (?)*; but a systematic search through the beds revealed the fact that the reddening of the shales was not original. It was noticed that the colour was deeper and richer in beds which were more micaceous. Specimens were also obtained which showed that while some portions were red, other parts were merely tinged, the central part being greenish grey, so that there is no doubt that the beds are stained. An explanation of the staining is obtained, if we suppose that rocks of Triassic age had originally extended over the Palæozoic floor beyond Calvert.

The band of red and green shales passed gradually downwards, through a thin belt of greenish-grey shales, into dark-grey shales which persisted to the bottom of the boring without any important change of colour, except where the beds were altered by the contact of the two small sills. Below the depth of 496 feet some few bands are highly micaceous, and some (but not all) of these bands are fossiliferous; on the other hand, fossils are not confined to them. The lamination is, in general, very imperfect, the rock splitting with an uneven or sub-conchoidal fracture; but, at frequent intervals, it splits with a perfection suggestive of slaty cleavage. That this fissility is not slaty cleavage is shown by its remaining parallel to the bedding as the dip varies (even in such a kink as that mentioned below). The planes of fissility are, in fact, slickensided surfaces due to differential movement along certain bedding-planes. Occasionally they show striations, in approximately the direction of dip; at other times the surface is uniformly polished; and in yet other cases there are irregularities that project above the general level, and take a high polish. In some cases the gradation from an ordinary rough bedding-plane to a highly slickensided surface can be traced within the sectional area of the core: the most beautiful example of this was at 1135 feet, in which case the zones of increasing polish were not parallel to the direction of dip, but to one of the joint-planes, at an angle of about 25° to the direction of dip. The distance apart of the slickensided bedding-planes varies from $1\frac{1}{2}$ or 2 inches to as much as 8 inches, in the higher part of the boring; but towards the bottom they come much closer together, being sometimes less than half an inch apart. Slickensides oblique to the bedding are sometimes seen.

The bedding-planes in the grey shales are occasionally covered by thin films of yellow-brown calcite: either in a continuous sheet, or in scattered circular patches which present a deceptive resemblance to crinoid-ossicles.

Cone-in-cone structure appears at several levels. In one case

(of which the depth-record is lost, but it should probably be about 900 feet) it is associated with a divergence of the laminæ of the shale which results in a false appearance of overthrust.

Occasionally well-marked joints are seen to cross the cores. Where the shales are vertical (1180 to 1220 feet) there are two main joints, at right angles to the bedding and to one another, and running the one almost vertically and the other horizontally; while a third, less perfect joint, runs at an angle of about 45° both to the bedding and to the horizontal joint. Where the beds are inclined, the main joints are at right angles (or nearly so) to the bedding, but not one to the other; and they are oblique to the direction of dip, the angle which they make with it varying in different cases from 25° to 60°.

After making allowance for the dip, the true thickness of these shales between the base of the Lias and as far as the Eastern Boring penetrated them, is about 480 feet. The dip varied from 40° up to 90°, and there were occasional kinks in the bedding, as for instance at 845 feet, where the general dip was 40°, but it was bent up to 80° about the middle of the core. An effort was made by Mr. Hiorns to ascertain the direction of dip, but the preliminary experiments were so unsuccessful that the attempt was abandoned.

The following fossils were found:—

Clonograptus tenellus var. *callavei* (Lapworth) at the depths of 496, 498, 517, 530, 555, 568, 600, 630, and 635 feet.

Clonograptus (?) at 490, 830–850, and 1160 feet.

Bryograptus (?) at 600 feet.

Obolella (?) aff. *salteri* Holl. (see p. 303), at the depths of 498, 555, 558, 609, 740, and 790 feet (at the last two levels, fragments only).

Worm-castings, at 960 feet.

Black, probably carbonaceous patches (remains of algæ?) frequently occur.

Clonograptus tenellus var. *callavei* (Lapworth) is known from the Shineton Shales of Mary Dingle (Shropshire), and from Zone 2 (*Bryograptus* Zone) of the *Ceratopyge* Beds of Scandinavia.[1] The Calvert specimens at the higher levels are well-preserved and quite characteristic, and an exceedingly fine specimen is in the possession of the Museum of Practical Geology (26239). Mrs. Shakespear writes of them:—

'The rock is so similar to that typical of the Tremadoc in Shropshire that it is difficult to believe that the specimens do not come from Mary Dingle.'[2]

The presence of *Clonograptus* leaves no room for doubt that the shales belong to the Lower Tremadoc Series.

The nearest localities where rocks of the same age are known

[1] J. C. Moberg & C. O. Segerberg, 'Bidrag till Kännedomen om *Ceratopyge*-Regionen' Medell. från Lunds Geol. Fältklub, ser. B, No. 2 (1906).

[2] *Bryograptus* is very doubtfully represented by two fragments showing the sicula. Mrs. Shakespear writes: 'I am inclined to think that they are only the proximal end of a *Clonograptus*, so preserved that the stipes are pendent rather than spread out horizontally. This appearance is not uncommon, and the small fragment shows thecæ of precisely the same form as those of *Clonograptus*.'

are: (1) Merevale (Warwickshire), over 50 miles north by west from Calvert; (2) Bronsil (Herefordshire), 60 miles west by north; and (3) Shineton (Shropshire), over 80 miles away to the north-west. The new discovery, therefore, extends very considerably the area over which Tremadoc Beds can be affirmed to have been originally deposited, as there is no reason to doubt that these four widely-separated occurrences were originally continuous.

We have no intention of entering into the discussion whether the Tremadoc Beds are more naturally grouped with the Cambrian or with the Ordovician. If, in the course of this paper, we refer to them as Cambrian, it is solely for convenience: for, in their geographical distribution in Britain, the Tremadoc Beds accompany the Cambrian, and not the Ordovician.

(ii) The Igneous Rocks. [A. M. D.]

Two sills, each about 2 feet thick, penetrate the Tremadoc Shales within a few feet of the principal fossil-bands, breaking across the bedding within the diameter of the core. The effect of the intrusions on the sediments is slight, but those that rest immediately on the sills are considerably baked and altered into a hard dark-grey shale, which is also veined with calcite and pyrite. The sills are so much alike, that one description will serve for both. Each is a fine-grained, dull grey-green rock, except for the very thin selvage which is pale purple, shading off into white. The surfaces are flat, but have what might be termed an 'upholstered' appearance, there being depressions resembling those produced on a stuffed textile fabric by sewing down. There are many veins of calcite and pyrite, and on some joint-surfaces pyrite is also abundant. On examination with a lens, the rock an inch from the surface is seen to have a finely-granular structure; but towards the surface it becomes much more homogeneous, except for what appear to be scattered porphyritic crystals. These latter are found still in the thin surface-layer, through which many of them appear to protrude: these protrusions, together with hollows which are impressions of similar crystals, impart to the surface a spotted appearance, in addition to the colour-shading already mentioned. This, however, seems to be due to the fact that the actual surface of the sill usually adheres to the shales, so that what is seen is a surface of disruption within the thickness of the selvage.

In section under the microscope these sills show a very fine ground-mass of small felspar-laths and granules of an opaque mineral (magnetite?). Scattered through this are (1) medium-sized felspar-laths, about 0·5 mm. long; (2) many rounded grains which appear to be olivine-pseudomorphs, some in serpentine, some in dolomite or magnesite,[1] a few in serpentine with a dolomite or magnesite margin: the diameter of these varies from

[1] [This was originally described as calcite, but subsequent application of Lemberg's test showed that it was not.]

less than 0·1 mm. to 0·2 mm.; (3) larger olivine-pseudomorphs, idiomorphic, but with much parallel growth and large inclusions of groundmass: these vary in length from 0·4 mm. up to 1 mm.; they consist almost entirely of dolomite or magnesite. There is no recognizable pyroxenic constituent. (See Pl. XXXIII, fig. 4.)

As the contact with the shales is approached, the groundmass becomes perfectly isotropic. In an enclosure within an olivine-pseudomorph its structure can be most easily made out: here it consists of a colourless glass full of little brown translucent isotropic granules, of uniform size (rather larger than 1 μ). In the general groundmass there are two sizes of granules, the larger being about the size of the above but less translucent, and the smaller forming an immeasurably fine dust. There are also seen numerous oval structures which appear to be sections of ellipsoids lying with their long axes not quite parallel to the contact-surface (average dimensions, about 12 $\mu \times 9$ μ). These are outlined by a ring of the larger granules; they have a very faint green tint, a somewhat radial structure, and show the optical characters of chlorite. I can only interpret them, somewhat doubtfully, as elongate vesicles filled with secondary chlorite. Some others, of almost exactly similar appearance, are composed of dolomite or magnesite, while yet others are quite isotropic. (See Pl. XXXIII, figs. 5 & 6.)

These sills show no close resemblance to any of the igneous rocks of the Nuneaton district. They are more nearly paralleled by some of the andesitic olivine-basalt sills in the Malverns,[1] particularly one intrusive in the Black Shales of Pendock's Grove (M 102 of Prof. Groom's collection), and less closely by one in the Black Shales of White-Leaved Oak (M 119) and one in the Grey Shales of Bronsil (M 249).

Even from the nearest of these the Calvert sills differ in the following characters:—(1) The much finer grain of the groundmass; (2) the absence of any recognizable pyroxenic constituent; (3) the greater abundance of olivine-crystals and of the larger felspar-laths; (4) the much greater amount of dolomite or magnesite, and the very small amount of serpentine in the olivine-pseudomorphs.

(2) The Western Boring.

[J. P. & A. M. D.]

As nearly as can be determined, this boring is situated about 370 yards due west of the other. It was started, not at the natural ground-level, but at the bottom of an excavation about 70 feet deep, the measured difference of level between the two sites being 67 feet 8 inches. The log of the original boring made in 1904–1905 has already been printed[2]; and, as the descriptive terms

[1] T. T. Groom, Q. J. G. S. vol. lvii (1901) pp. 156–84.

[2] 'Iron & Coal-Trades Review' September 1st, 1911, pp. 316, 317. The statement therein that the brickworks excavation is 90 feet deep is taken from the log, and was probably a bad guess.

applied to the various strata passed through are somewhat misleading, no useful purpose would be served by reprinting them. Allowing for this difference of 67 feet 8 inches, we find a close agreement in the Jurassic rocks in the two borings; thus the following datum-lines can be recognized :—

	Western Boring.		Eastern Boring.		Difference.	
	Feet	*inches.*	*Feet*	*inches.*	*Feet*	*inches.*
Base of Oxford Clay ...	32	1	97	9	65	8
Base of Oolites	135	0	203	0	68	0
Base of Lias	380	0	443	6	63	6

Owing to the scanty nature of the information, however, detailed comparison is impossible; but the few remarks made in the log show that the beds generally resemble those of the Eastern Boring. Once below the Jurassic strata, we find a striking difference in the fact that in the Western Boring there was an uprush of inflammable gas, at a pressure of 60 lbs. to the square inch, which is still (June 1913) escaping, nearly nine years after it was first struck. There has been no trace of gas in the Eastern Boring.

The sinker's record of the Western Boring gives no details of the strata between 312 and 382 feet; but there can hardly be any doubt that (as suggested above) the gas had accumulated immediately below the base of the Lias at 380 feet. The record gives the following particulars below this level:—

Feet	*inches.*	
382	0	Soft red shale.
413	0	Mottled shale, 2 feet.
433	0	Mottled shale.
434	7	Blue shale.
437	7	Blue shale.
443	7	Blue shale.
440	0	Jointy shale and ironstone-bands, 2 feet 8 inches.
445	8	Do. do. do.

The general inference from the above is that, just as in the Eastern Boring, about 50 feet of stained Tremadoc Shales were passed through, and then the typical grey shale was reached. This is confirmed by the fact that, when the boring was re-started in 1911, the first material brought up was a very mixed-up sort of red mud, doubtless derived from the soft red or mottled shales at and below 382 feet. When this was washed, a sandy residue was left, quite like that from the mottled shales of the Eastern Boring. Cores were got from 456 feet 6 inches down to 649 feet, and all those that we have seen were essentially similar to the Tremadoc Shales of the Eastern Boring. Fossils were not abundant, but the following were found :—

Obolella (?) aff. *salteri* Holl, at 500, 515, 520, 523, and 524 feet respectively.
Clonograptus (fragments), at 523 feet.

Two questions arise out of a comparison of the two borings :—
(1) Is it possible to determine the strike of the Tremadoc Beds?
(2) What is the source of the gas in the Western Boring?

(1) The wide vertical range of the fossils in the Eastern Boring makes it impossible to identify any of the individual fossil-bands in one boring with those in the other. The igneous sills of the Eastern Boring were certainly not passed through in the Western Boring below 456 feet, but there is a possibility that the term 'ironstone-bands, 2 feet 8 inches' might refer to an igneous sill. Even if we could be sure of this, or identify any other horizon as occurring in both borings, it would not be safe to infer that the two borings were approximately in the same strike-line: for either a fold or a strike-fault might cause the repetition of the same horizon, even though the strike were north and south. We conclude, therefore, that no inference can be drawn as to the strike of the Tremadoc Shales.

If the gas-bearing strata in the Western Boring could be shown to be conformable upon the Tremadoc Shales, we might infer that the dip has a westerly component in its direction. What is known of the Tremadoc Beds of Warwickshire and the Malverns does not lend any support to such a view: it seems much more probable that the gas-bearing strata are unconformable upon the Tremadoc Shales, in which case no inference as to the dip of the latter can be drawn.

(2) Before the Western Boring was re-started, much trouble was taken to stop the outflow of gas, with such success that when later the lining tubes were withdrawn, it was some months before the gas again succeeded in escaping. From this it is evident that the gas is confined to strata of limited thickness, not extending to any great depth below the base of the Lias. It must come, therefore, from porous strata which thin out completely in the 370 yards between the two borings. The gas must have been effectually sealed down by the impermeable Liassic clay above; but, in order to account for the maintenance of a high pressure for so long a time, we must suppose not only that these eastward wedging-out strata are continuous with an extensive mass on the west, but that they must have a more or less westward dip. The thin edge of a downward-pointed wedge would be a very bad site for a gas-boring.

This would seem to suggest a Palæozoic age for the gas-bearing strata, since the Mesozoic beds of this region have a normally south-eastward dip; and it is by no means impossible that the gas may come from either Devonian (Old Red Sandstone) or Carboniferous strata, resting unconformably upon the Tremadoc.

While fully recognizing this possibility, we nevertheless incline to another view. We have already pointed out that the great depth to which the Tremadoc Shales are stained red and green in both borings suggests that Triassic strata may once have covered them. If so, may it not be that we have here actually the feather-edge of the Trias? Such a feather-edge would be continuous with an extensive mass to the westward, and its dip would not be the tectonic dip of the later Mesozoic strata, but the dip of original deposition on the Palæozoic floor, which sinks north-westwards.

Natural gas occurs in the salt-bearing Trias (Keuper) of Durham, where it overlies the Permian Magnesian Limestone:—

'The presence of bitumen, rock-oil, inflammable gases, or hydrogen sulphide in the [Keuper] beds below the salt is often assumed to indicate underlying Coal Measures from which they are supposed to be derived. But this inference has proved erroneous again and again on Tees-side.'[1]

With this warning before us, it may seem very rash to suggest that the Calvert gas may have leaked into porous Triassic strata from underlying Coal Measures, possibly at some distance to the west or north-west. We only mention it here as a possibility, the less unlikely in view of the published analysis,[2] which shows the Calvert gas to resemble that obtained from Wigan cannel-coal.

III. Palæontological Notes. [A. M. D.]

Nuculana cf. quenstedti (Tate).

Leda quenstedti R. Tate, 1870. 'List of Irish Liassic Fossils' App. I, 7th Ann. Rep. Belfast Nat. F.-C. p. 19 & pl. i, fig. 4.

These forms occurred at several horizons between 203 and 300 feet (*algovianum* to *striatum* zones)—showing very slight variations, which may possibly prove to have zonal value. They are smooth shells, with very delicate growth-striations, rounded in front, and with only the slightest tendency to rostration behind. Such forms have been, in England, commonly identified as *Leda galatea* d'Orb., without sufficient justification, as no figure or adequate description of that species was given by A. d'Orbigny.[3] They are very near to Dr. Kitchin's 'sp. B' from the *capricornus* zone of the Brabourne Boring,[4] but differ slightly in proportion of height to length. They are not identical with Tate's species, which is Hettangian; but, pending a more careful zonal study than can now be given to them, it is undesirable to propose a new name.

Orbiculoidea aff. holdeni (Tate). (Fig. 2, p. 330.)

Discina holdeni R. Tate, 1867. Q. J. G. S. vol. xxiii, p. 314.
Discina holdeni Tate, 1874. Davidson, 'Brit. Foss. Brach. Suppl. Jur. & Triass. Brach.' Monogr. Pal. Soc. p. 85 & pl. x, figs. 12–12 *c*, pl. xi, fig. 32.

This little brachiopod is represented only by a number of immature brachial valves, the largest of which are about 3·5 mm.

[1] T. Tate, 'Notes on Recent Borings for Salt & Coal in the Tees District' Q. J. G. S. vol. xlviii (1892) p. 489.

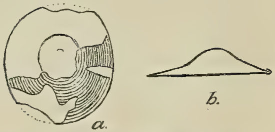
[2] 'Iron & Coal-Trades Review' Sept. 1st, 1911, pp. 316, 317.

[3] [M. A. Thévenin, who is figuring the types of d'Orbigny's "Prodrôme" in the 'Annales de Paléontologie' has kindly written to inform me that the type of *Leda galatea* is broken in front, and to express the opinion that Dumortier's figure should be taken as the type ('Études paléont. sur les Terr. Jurass. du Bassin du Rhône' pt. 3, 1869, p. 120 & pl. xix, figs. 5, 6). Those figures indicate a form related to, but by no means identical with, the Calvert and Brabourne specimens.—*A. M. D., June 12th, 1913.*]

[4] *Nuculana* sp. B, F. L. Kitchin, 1911: 'Mesozoic Rocks in some of the Coal-Explorations in Kent' Mem. Geol. Surv. p. 175.

in diameter. It agrees with *O. holdeni* in the central position of the umbo, but differs in the more nearly circular outline, the ratio of length to breadth being 8 : 7 instead of 5 : 4. It is not quite so nearly circular as *O. davidsoni* Moore. A noticeable feature in the best-preserved specimen is the somewhat inflated apical region, as shown in the profile (fig. 2 *b*).

Fig. 2.—Orbiculoidea *aff.* holdeni *Tate (431–432 feet).*



[*a* = Brachial valve, external view. *b* = The same in profile. Both × 8.]

This shell may perhaps be identical with the form mentioned but not named by Davidson ('Brit. Foss. Brach.' Monogr. Pal. Soc. vol. v, p. 279), found by Brodie in the Lower Lias (*Lima* beds and shales, that is, lowest Sinemurian) of the Vale of Gloucester and Harbury.

Charmouthian—*jamesoni* or *valdani* zone, at 431–432 feet, Calvert Boring. Coll. A. M. Davies.

Obolella (?) aff. salteri Holl. (Fig. 3, p. 331.)

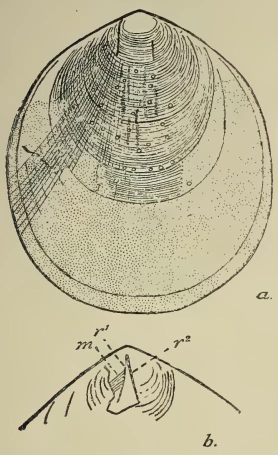
1865. *Obolella salteri* Holl, Q. J. G. S. vol. xxi, pp. 101, 102 & fig. 9.
1866. *Obolella salteri* Davidson, 'Brit. Silur. Brach.' Monogr. Pal. Soc. pt. vii, No. 1, p. 61 & pl. iv, figs. 28–29.
1902. *Obolella (?) salteri* Matley, Q. J. G. S. vol. lviii, pp. 138–140 & figs. 3–6.

Form broadly ovate; length = 6·25 mm., greatest breadth the same or very slightly less, at 3 mm. from the umbo. Pedicle and brachial valves closely similar, the former having the umbo slightly more pointed.

Surface ornamented with fine concentric lines, which appear to be the only markings on the outer surface, but the outer shell-layer is only preserved in fragments; where it is removed, the exterior of the inner layer shows, crossing the fine concentric lines, very delicate radial lines, in addition to which there are much coarser and rather indefinite radial corrugations, four or more in number, appearing at about 1 mm. from the umbo, dying away at about 3 mm. from it, and occupying a breadth of about 0·75 mm. on each side of the middle line. There are also seen, on the same surface, a number of minute pustules, scattered in an irregular manner over an area somewhat larger than that occupied by the corrugations. Dr. Matley, to whom the specimens were shown, suggested that these might be the bases of spines, but no evidence of spines could be found. The irregularity of these pustules, and the fact that each one is surrounded by an aureole in which the brown colour of the shell is replaced by white, suggested the idea that they might be due to minute boring organisms.

Pedicle- and brachial valves in a few cases occur together, somewhat displaced from the natural position. In the majority of cases only the outer surface of a single valve can be seen; and in nearly every case this is the brachial valve, but one unquestionable

Fig. 3.—Obolella *(?) aff.* salteri *Holl.*



[*a* = Brachial valve, external view. (Museum of Practical Geology: 26235.) Drawn on the basis of a photomicrograph by Mr. H. G. Smith. The stippling represents the portion from which the shell has exfoliated. The drawing is so far diagrammatic that appearances that cannot all be seen by the same illumination are represented on different parts of the surface. ×8.

b = Interior of the umbonal region of another brachial valve. (Museum of Practical Geology: 26355.) r^1, r^2 = diverging ridges; *m* = muscular impression. The irregular line to the left of *m* and the line r^2 form the boundaries of the only remaining fragment of the innermost shell-layer. × 9.]

pedicle-valve having been recognized.

The only information on the internal structure was obtained from two brachial valves, in both of which the innermost shell-layer was lost except close to the umbo. Here may be seen two slight ridges, diverging at an angle of about 24°; on the outer side of one there are a few striations of muscular attachment (*m* in fig. 3 *b*). The sub-symmetrical cracks on each side of the umbo, seen in fig. 3 *a*, may have some relation to the internal structure.

Holl's type appears to be lost, and the most satisfactory account of the species is that given by Dr. Matley, based on topotypes from Malvern. Although we are not satisfied that the Calvert species is actually identical with any figured specimen, and had given it a MS. name as a new species; yet, since the range of form-variation of *O. salteri* as figured by Dr. Matley is wide, it seems advisable for the present to leave our specimens under the name *O. (?)* aff. *salteri* Holl.

The genus *Obolella* is stated by Walcott to be confined to the Lower Cambrian; and the Scandinavian forms identified as *O. salteri* are placed by him in the new genus (or subgenus of *Obolus*) *Bröggeria*. It is by no means certain that these forms are the same as the British species; therefore we leave the Calvert form under the generic name *Obolella (?)*.[1]

[1] [Since this paper was read, I have seen Dr. Walcott's Monograph on the Cambrian Brachiopoda (U.S. Geol. Surv. Monogr. vol. li, 1912). Dr. Walcott accepts the Swedish and American type-species of the sub-genus *Bröggeria* Walcott as identical with *Obolella salteri* Holl. As I am not convinced of the identity of the Calvert species with any of the Swedish and American specimens figured (*op. cit.* pl. xiii, figs. 1 *a–n* & pl. xv, figs. 4 *a–d*) I leave the name unaltered.—*A. M. D., June 20th, 1913.*]

Horizon.—Lower Tremadoc (Shineton) Shales, zone of *Bryograptus*, at depths of 555 and 600 feet, Calvert Boring.

Specimens in the Museum of Practical Geology, Jermyn Street, London (26233–4–5, 26355), and in the collection of A. M. Davies.

IV. The Bletchley Boring. [A. M. D.]

Bletchley lies a little over 12 miles from Calvert in an east-north-easterly direction, or approximately along the strike of the Oxford Clay.[1] It is, therefore, of interest to compare the two borings, and see whether that at Calvert may throw light upon that at Bletchley. The latter was described by Mr. Jukes-Browne in 1889.[2] Unfortunately, only fragments of the rocks passed through seem to have been preserved, and no species of fossils were identified. The following is a statement of the strata passed through, condensed from the engineer's section, but expanded by means of Mr. Jukes-Browne's detailed descriptions where necessary for a comparison with Calvert :—

Nos.		*Thickness* (*in feet and inches.*)		*Depth* (*in feet and inches.*)	
1–8.	Clay, with some bands of limestone	192	0	192	0
9.	Dark-grey limestone, with well-marked oolitic structure, echinoderm- and shell-fragments	12	0	204	0
10.	Blue clay	8	0	212	0
11.	Blue limestone, partly oolitic	5	9	217	9
12.	Blue clay	6	3	224	0
13.	Light-grey crystalline limestone, very hard; echinoderm-fragments	1	0	225	0
14–20.	Mainly blue clay, with some limestone-bands and septaria	131	0	356	0
21.	Indurated bluish limestone, very hard	22	5	378	5
22–25.	Sandstone with boulders of granitic rock, and beds of clay	31	7	410	0

The generally-accepted interpretation of this section is that proposed by Mr. Jukes-Browne and Mr. Cameron, that the upper 356 feet belong to the Oxford Clay, and the bottom 54 feet to the Kellaways Rock, the granitic rock (of Charnian character) occurring as boulders in the latter. In support of this view the three main facts are: (1) the similar salinity of the water from the lowest 30 feet, and that from wells in the Kellaways Rock of Bedfordshire; (2) the similarity of Bed 21 to a bed in the Kellaways Rock of Kempton; and (3) the fact that the bottom 50 feet of clay (18, 19, & 20) were full of 'just such fossils as would occur near the base of the Oxford Clay.' As to (1), it may be pointed out that saline waters are common in Jurassic rock-beds in this area; they have been got from the Forest Marble at Swindon,

[1] [Since the reading of this paper, I have visited the nearest large exposure to Bletchley, that at the Newton Longville brickfield, $1\frac{1}{2}$ miles away to the west-south-west, and find *ornatum*-zone fossils at a depth of about 25 feet below the surface.—*A. M. D., April 4th, 1913.*]

[2] Geol. Mag. dec. 3, vol. vi, pp. 356–57.

from some part of the Lower Oolites at Oxford, and from the Corallian in many places,[1] as well as from the Kellaways Rock. As to (2), the comparison seems to be based upon the engineer's description only, no specimen of the Bletchley rock having been preserved. As to (3), we read that

'all the larger specimens were broken up by the chisel; those preserved are chiefly fragments of the stems and arms of small crinoids, with several pieces of small belemnites and fragments of bivalve shells,'

which might quite well be Liassic.

On the other hand, Prof. P. F. Kendall has pointed out[2] the

'difficulties involved in any attempt to interpret this boring and to bring it into accord with the . . . borings at Stony Stratford. . . . These two borings' [he remarks] 'indicate the presence of a normal series of Oolite and Lias within 5 miles of the Bletchley boring, and the intervening distance, 5 miles, is insufficient to explain the absence of at least some of the beds at Bletchley, just as the normal dip of the Oxford Clay in the district would not account for the presence of so great a thickness of the Oxfordian beds. I suspect that some beds of greater geological age than the Oxford Clay occur in the lower part of the Bletchley borehole.'

To the difficulties pointed out by Prof. Kendall, we would add the lithic character of Nos. 9–13. In these beds, which on the usual interpretation are in the middle of the Oxford Clay, out of a total thickness of 33 feet, 18 feet 9 inches consist of oolitic and crystalline limestones. These invite comparison with the Forest Marble of the Calvert Boring, and we suggest the following correlation of the two borings:—

	Calvert.		Bletchley.
	Feet	*inches.*	*Feet.*
Oxford Clay	93	3	192
Forest Marble	38	9	33
Great Oolite, etc.	67	0	absent ?
Lias (Charmouthian) ...	240	6	185

This new interpretation dispels the difficulties pointed out by Prof. Kendall, and justifies his suspicion that older rocks than Oxford Clay were present. We may also now feel more confident than before that the Bletchley Boring, if it did not actually touch the Palæozoic floor, came extremely near to it; and we may safely assign to it a level a little deeper than -150,[3] which is practically identical with that at Calvert. We may also infer that the Palæozoic floor, in the near neighbourhood, consisted of Charnian igneous rocks.

[1] H. B. Woodward, 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iv (1894) pp. 513, 515 & vol. v (1895) pp. 340, 341.

[2] Final Rep. Royal Comm. on Coal-Supplies, pt. ix (1905) p. 25.

[3] According to the engineer's record, the well started about +260 feet, and the boring went to a depth of 410 feet. In the Royal Commission's Report, and in 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. v (1895) p. 48, the depth is given as 419 feet. The former figure has been taken.

V. The Palæozoic Floor north of the Thames. [A. M. D.]

The time has come when it may be useful to take stock of the knowledge already gained from scattered borings as to the depth of the Palæozoic floor, and to express known facts and probabilities in the form of a contoured map. Where Triassic deposits rest upon it, this floor probably has the uneven form of a buried land-surface, much too irregular to be contoured from scattered observations; but, where marine strata directly overlie it, it is probably a smooth peneplain—either of prolonged subaërial or of marine denudation. Further, where Trias is present, its deposition must have levelled up the irregular land-surface to another smooth plain. In short, the base of the marine Mesozoic (of whatever age, from Rhætic to Gault) must form a sufficiently continuous smooth surface to be contoured from its known outcrop to the depths at which it is met in borings. This is what has been attempted in Pl. XXXIV. Where Trias is absent, the contours are those of the Palæozoic floor.

On the same map have been indicated, as far as the scale would allow, all the mapped folds and faults in the Mesozoic rocks, and the chief of those in the exposed Palæozoic rocks. These are of importance for a consideration of the possible tectonic structure of the buried Palæozoic floor, if that of its Mesozoic cover corresponds to it in any degree.

The danger of assuming too simple a structure in the buried Palæozoic floor is evident, if we consider the repeated series of earth-movements to which its constituent rocks may have been subject:—

(1) Post-Tremadoc movements, indicated by the absence of Ordovician rocks south-east of Shropshire;
(2) Post-Lower Devonian movements, indicated by the barrier between the Midland and South-Western Provinces, and the unconformable sequence of Coal Measures on Lower Old Red Sandstone in South Staffordshire and elsewhere [1];
(3) Repeated intra-Carboniferous movements shown by the zonal work of Dr. Vaughan, Dr. Sibly, and Mr. Dixon, by the overstep of Lower Carboniferous by Upper Coal Measures in the Forest of Dean,[2] and by local irregularities in the Midlands [3];
(4) Post-Carboniferous movements.

The most striking example of continuity of tectonic lines from the Palæozoic area into the Mesozoic area is afforded by the western boundary-fault of the Warwickshire Coalfield, which has a north-and-south or Malvernian trend. This is carried on through the Trias of the Forest of Arden in the form of the easternmost

[1] W. W. King & W. J. Lewis, Geol. Mag. dec. 5, vol. ix (1912) pp. 487, 488.
[2] T. F. Sibly, *ibid.* pp. 417 *et seqq.*
[3] 'The rocky floor upon which the Carboniferous rocks of the Midlands were deposited seems to have been greatly affected by the action of local crust-creep during Carboniferous time': C. Lapworth & W. W. Watts, 'Geology of the Birmingham District' Proc. Geol. Assoc. vol. xv (1898–99) p. 364.

syncline and anticline mapped by Dr. Matley.[1] Further continuation of the anticline is suggested by the levels of the Liassic outcrop near Stratford-on-Avon, and this is in line with the well-known Vale-of-Moreton Anticline. Batsford Boring, which proved Coal Measures on Silurian, is on the Vale-of-Moreton axis. West of the axis is the remarkable sag, proved in the Mickleton Boring, where the base of the Rhætic was at − 815 feet O.D., although 5 miles away to the north-east, 6 miles to the north-west, and 10 miles to the west the same horizon crops out at about + 100. As the levels of the Middle Lias are not recognizably affected, and the Lower Lias proves to have the enormous thickness of 1241 feet, it seems likely that we have here a case of Liassic faulting masked by contemporaneous sedimentation. The other side of the trough may be a line of Charnian trend in continuation of the Lickey axis. There are some slight suggestions of this (see Pl. XXXIV). Farther south of the same region, the Bajocian flexures mapped by Mr. Buckman have a Charnian trend.[2]

The strike of the Cambrian rocks on the eastern side of the Warwickshire Coalfield shows a variation between Malvernian and Charnian, between north-west by west and north by west. They have approximately the latter trend as they disappear underneath the Trias near Bedworth, and the Brandon Boring shows its continuance to the latitude of Rugby.[3] If we may consider the faults in the Jurassic rocks near Harbury and Cropredy as a key to the structure beneath, the trend may have returned there to a Charnian direction, which, if continued, would carry the Cambrian towards Bletchley, or with a subsequent return to Malvernian, towards Calvert.

In the Triassic area of South Leicestershire, inliers and borings show the presence of a variety of Palæozoic rocks—unproductive Coal Measures, Millstone Grit, Carboniferous Limestone (Viséan), Cambrian, and Charnian igneous rocks. Continuation of this mixed belt in a south-easterly direction is suggested by the Viséan of Kettering Road, Northampton, and the Charnian igneous rock of Bletchley. Lastly, the strike of Charnwood Forest leads to the Charnian igneous rock of Orton Boring. There is, however, a belt, at least 10 miles wide, curving round from Cheltenham towards Northampton, in which the numerous faults are disposed athwart the supposed Malvernian-Charnian lines. South of this belt, a Charnian direction is again seen in the post-Jurassic pre-Cretaceous folds of the Swindon and Oxford-Aylesbury districts. In view of this transverse belt, and the absence of any clear indication of a Charnian strike in the comparison of the two borings at Calvert, it would be very hazardous to assume the continuity of Warwickshire conditions so far as Calvert.

[1] Q. J. G. S. vol. lxviii (1912) fig. 7, p. 270.

[2] At Daylesford, on the eastern side of the Vale-of-Moreton Anticline, conglomeratic marlstone with Palæozoic pebbles offers a problem for solution. See E. Hull, 'The Geology of Cheltenham' Mem. Geol. Surv. 1857, p. 20; also L. Richardson, Proc. Cotteswold Nat. F.-C. vol. xvii (1911) p. 200.

[3] R. D. Vernon, Q. J. G. S. vol. lxviii (1912) p. 611 & pl. lxi (map).

The question of greatest general interest suggested by the Calvert borings is whether productive Coal Measures may be present in that portion of the Palæozoic floor which they have shown to come so unexpectedly near the surface. The answer to this question must at present be very uncertain, and I would simply make the following remarks:

(1) The Midland Coal Measures show evidence, by the coalescence of seams, attenuation, and overlap towards the south, that a barrier of older rocks must exist in that direction. The occurrence of productive Coal Measures at Burford (whether they are productive or unproductive at Batsford does not appear from the published statement) shows that by that latitude the barrier has been crossed.

(2) Carboniferous Limestone is known to occur at Northampton, and, by inference from the pebbles in the Permian conglomerates,[1] also beneath the Forest of Arden or its neighbourhood. Its absence at Batsford, half way in a straight line between Northampton and the Forest of Dean, along with its overstep by Coal Measures between that Forest and the Forest of Wyre, renders it quite possible that in the Calvert area Coal Measures might rest directly upon the Cambrian rocks. In this connexion it may be noted that the Lias of Calvert, while showing relations to that of the Radstock area in respect of its overlap, shows neither the attenuation nor the calcareous composition which are there associated with nearness to an extensive mass of Carboniferous Limestone.

Further knowledge is needed before any definite conclusion as to the existence of Coal Measures can be reached; and the shallow depth of the Palæozoic floor makes that further knowledge comparatively easy to obtain.

Mesozoic Overlaps on the Palæozoic Floor.

It may be useful to summarize here what is known as to the progressive submergence, with interruptions of partial emergence, of the Palæozoic floor of the South-East of England.

(1) The Charmouthian overlap (hemeræ *raricostati* to *jamesoni*) is now known at Calvert and at Brabourne; reasons have been given for believing it to exist at Bletchley also; and, from an examination of the Ropersole cores, it is thought that when the fossils are extracted and identified they will prove it there also. At Calvert there must have been a temporary submergence in the hemera *raricostati*, followed by a short emergence before the main *jamesoni* transgression. Similar oscillations are known to have occurred in the Radstock area, where remanié fossils of the *raricostatum* zone are found at the base of the *armatum* zone in some places, though in others the former zone is present. At Vobster it rests upon the Carboniferous Limestone: elsewhere in the

[1] H. T. Brown, Q. J. G. S. vol. xlv (1889) p. 27 & table on p. 24; W. W. King, *ibid.* vol. lv (1899) pp. 122, 123.

Radstock area one or other of the lowest Charmouthian zones rest upon the *obtusum* or *semicostatum* zone of the Sinemurian.

(2) A later Charmouthian overlap (hemera *capricorni*) occurs at Dover.

(3) At Calvert and Oxford, and (if my interpretation be correct) at Bletchley, there is evidence of a post-Charmouthian emergence, causing the very marked non-sequence between at least a high zone of the Vesulian and the lowest zone of the Domerian. It would be interesting to know in what manner this gap gradually becomes filled up between Calvert and the outcrop in the Banbury district. Future borings may perhaps add much to our knowledge, and enable us to date with some precision alternate advances and withdrawals of the sea over this area. For the present, we only know that the non-sequence is split into two: for, while at Fritwell the *Trigonia-signata* Beds rest on Upper Liassic Clay with *Dactylioceras*,[1] at Brackley the Upper Lias rests directly on the *margaritatus* zone.[2] This disappearance of the *spinatum* zone (which I suspect also at Stratton Audley and Stony Stratford from the published accounts[3]) is remarkable, in view of the fact that at Mells in Somerset the *spinatum* zone appears to overlap on to the Palæozoic.[4] When emergence in one area is thus contemporaneous with submergence in another, it is evident that broad movements of the sea-level cannot alone explain the facts: local crust-movements must have been taking place.

(4) The repeated oscillations that produced the numerous non-sequences in the Inferior Oolite do not appear to have left any trace in the East of England. Even the *garantiana* overlap, which is so widespread in the West of England and touches the Palæozoic at Nunney, did not reach as far east as Calvert. It was not until late in the Vesulian age that the area of deposition once more extended to that point: it may have reached Brabourne at about the same time. In neither place does it attain the Palæozoic floor itself: Vesulian rests upon Toarcian at Brabourne, upon Domerian at Calvert.

(5) The Bathonian overlap (*circa* hemera *bathonicæ*) upon the Palæozoic floor is known under London (at Meux's Brewery), and at Richmond and Streatham. It may have been about the same time, or somewhat later, that Charmouthian beds were re-submerged at Bletchley. At Dover the date was probably earlier.

(6) The Callovian overlap (hemera *macrocephali*), which is of so much importance abroad, is unknown in England, if the old

[1] I am indebted to Mr. J. Pringle for this information.

[2] I am indebted to Mr. E. A. Walford for this information in advance of publication.

[3] H. B. Woodward, 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iv (1894) pp. 391, 493.

[4] C. Moore, Q. J. G. S. vol. xxiii (1867) pp. 580–81.

interpretation of Bletchley is abandoned. On the contrary, it is found at Calvert (and probably at Bletchley) that a non-sequence occurs between Oxford Clay and Forest Marble, as though the Callovian age were a time of emergence. In this connexion it may be recalled that in various parts of the outcrop there is no evidence of Callovian, while the *anceps* zone of the Continent is scarcely known in Britain.[1] Along the outcrop, however, the Cornbrash is one of the most constant of formations: its absence at Calvert was a great surprise.

(7) No later Jurassic overlap is known, and the next is the Wealden overlap, known on the Palæozoic floor at Ebbsfleet only. At Dover, Wealden rests upon Kimmeridgian.

(8) The Aptian overlap (hemera *deshayesii*?) occurs at Culford on the north and Cliffe on the south; also upon Jurassic strata at Richmond, Chatham, Bobbing, and Chilham.

(9) The Albian overlap (hemera *interrupti* or later) is shown at Harwich, Stutton, and Weeley, at Ware, Cheshunt, Kentish Town, and Crossness (and upon Jurassic strata at Saffron Walden, Meux's Brewery, and Streatham). With this, the Palæozoic floor and its Jurassic cover were in all probability finally submerged.

VI. Summary.

The most important new facts recorded in the present paper are these:—

(1) The shallow depth at which the Palæozoic floor lies at Calvert—$443\frac{1}{2}$ feet below the surface, or $153\frac{1}{2}$ feet below sea-level.

(2) The presence in North Buckinghamshire of Lower Tremadoc Beds (Shineton Shales) with *Clonograptus*.

(3) The absence of Triassic (except possibly in the Western Boring), of Hettangian and Sinemurian, and the direct superposition of the Charmouthian (*jamesoni* zone) upon the Palæozoic floor.

(4) The absence of all but the lowest portion of the Domerian (Middle Lias of the Geological Survey), of the whole of the Toarcian, Aalenian, and Bajocian (Upper Lias and most of the Inferior Oolite), and the superposition of a high zone of the Vesulian (Chipping-Norton Limestone) upon the *algovianum* (lower *margaritatus*) zone of the Domerian.

(5) The absence of a portion of the Swerford Beds, the Neæran Beds, and probably of a small portion of the Great Oolite.

(6) The absence of Cornbrash and Callovian, the *ornatum* zone of the Oxfordian resting directly upon the Forest Marble.

[1] See S. S. Buckman, 'Summary of Progress for 1911' Mem. Geol. Surv. 1912, pp. 62, 63.

TABLE OF BORINGS SHOWN IN PLATE XXXIV.

No. on Map.	*Locality.*	*Depth in feet below O.D. of base of marine Mesozoic.*	*Formation below marine Mesozoic.*	*Greatest depth in feet below O.D.*	*Lowest formation reached.*
1.	Mickleton	−815	Keuper Marl.	− 842	Keuper Marl.
2.	Batsford	−130	Keuper Marl.	−1330	Silurian.
3.	Burford Signett	−367 +	Trias.	−1060	Coal Measures.
4.	Oxford	Not reached.	——	− 249	Lias (Charmouthian).
5.	Calvert	$-153\frac{1}{2}$	Tremadocian.	−1108	Tremadocian.
6.	Bletchley	−150 ?	Charnian ?	− 150	Charnian ?
7.	Gayton	−335	Keuper Marl.	− 712	Old Red Sandstone.
8.	Northampton (Bridge Street)	−405	Trias.	− 459	Trias.
9.	Northampton (Kettering Road)	−460	Trias ?	− 573	Carboniferous Limestone (Viséan).
10.	Kingsthorpe	−506	Trias ?	− 593	Trias ?
11.	Orton	−317	Trias.	− 415	Charnian.
12.	Rugby	−110	Keuper Marl.	− 785	Keuper Sandstone.
13.	Brandon	Started on Trias.	Keuper Marl.	$-96\frac{1}{4}$	Coal Measures.
14.	Loughton	Not reached ?	——	−1006	Gault ?
15.	Cheshunt	$-870\frac{1}{2}$	Devonian.	− 900	Devonian.
16.	Ware	$-686\frac{1}{2}$	Wenlockian.	$-721\frac{1}{2}$	Wenlockian.
17.	Saffron Walden	Not reached.	——	− 804	Jurassic (Oxfordian ?).
18.	Culford	$-527\frac{1}{2}$	Palæozoic.	$-547\frac{1}{4}$	Palæozoic.
19.	Coombs	Not reached.	——	− 735	Gault.
20.	Stutton	−974	Palæozoic.	−1495	Palæozoic.
21.	Harwich	−1023	Palæozoic.	−1092	Palæozoic.
22.	Weeley	−1004	Palæozoic.	−1049	Palæozoic.

The following are the chief suggestions of a more theoretical character :—

(1) That the gas-bearing strata of the Western Boring are Triassic, the actual margin of that system lying between the two borings at Calvert. (The alternative possibility that those strata are Upper Palæozoic is considered.)

(2) That in the Bletchley Boring Oxford Clay, Forest Marble, and Lower Lias are present.

(3) A contoured map of the Palæozoic floor is presented, as a basis for future discussion.

(4) Suggestions are made as to the structure and composition of the Palæozoic floor.

EXPLANATION OF PLATES XXXIII & XXXIV.

Plate XXXIII.

Microscope-sections of rocks from the Calvert Eastern Boring.

Fig. 1. Bottom bed of Great Oolite, at 195 feet: × 23. In the centre is a rounded fragment of oolitic limestone, with a coating of calcite, dusky marginally, and partly worn away. Derived oolite-grains with dusky margins are scattered through the matrix. (See p. 318.)

2. Sandy beds in Chipping-Norton Limestone, at 201 feet: × 23. In the centre is a subangular derived fragment of oolitic limestone with dusky margin. (See p. 319.)

3. Same beds: × 17. In the centre is an oolite-grain indented by angular quartz-grains; around are oolite-grains and fragments, with dusky margins. (See p. 319.)

4. Olivine-basalt sill at 606 feet: × 20. Porphyritic olivine-pseudomorphs in calcite, showing parallel growth and zonal inclusions; groundmass with felspar-laths and minute opaque granules. (See p. 326.)

5. Selvage of the same sill: × 22½. Margin on the right; across the centre a calcite-vein; the dark patch below this is probably an inclusion of shale; olivine-pseudomorphs in calcite; felspar-laths. (See p. 326.)

6. Portion of the same: × 90. Felspar-laths; vesicles (?) filled with chlorite; groundmass.

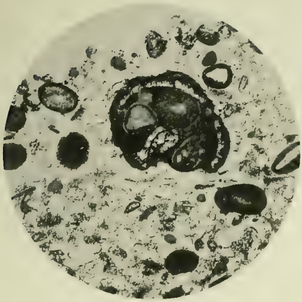
Plate XXXIV.

Map of part of South-Central and South-Eastern England, on the scale of 10 miles to the inch, or 1:633,600.

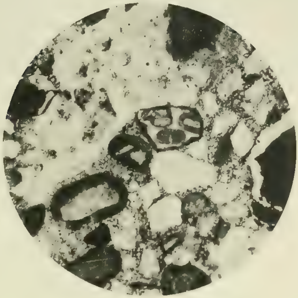
The contour-lines give the estimated depth of the base of the marine Mesozoic strata (Gault or Jurassic) above or below Ordnance datum. To the south-east of the dotted line (approximate south-eastern limit of Trias) they are also contour-lines of the Palæozoic floor.

The localities to which the numbers on the map refer are enumerated in the table on p. 339. The figures at the side, if not followed by a letter, denote the depth below O.D. of the Palæozoic floor immediately beneath marine Mesozoic strata; when followed by a   , they denote the depth below O.D. at which marine Mesozoic strata rest upon Trias; when followed by a **J**, they denote the depth below O.D. at which the boring ended in Jurassic strata.

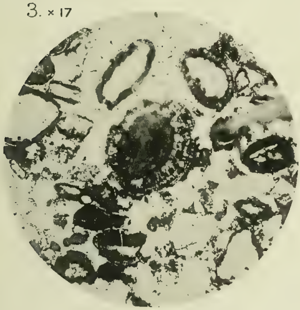
1. × 23



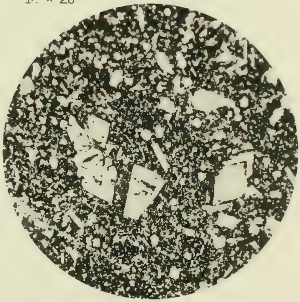
2. × 23



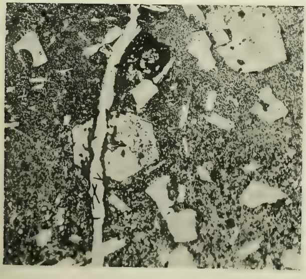
3. × 17



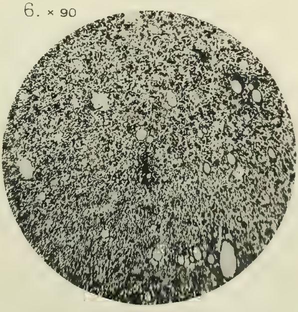
4. × 20



5. × 22½



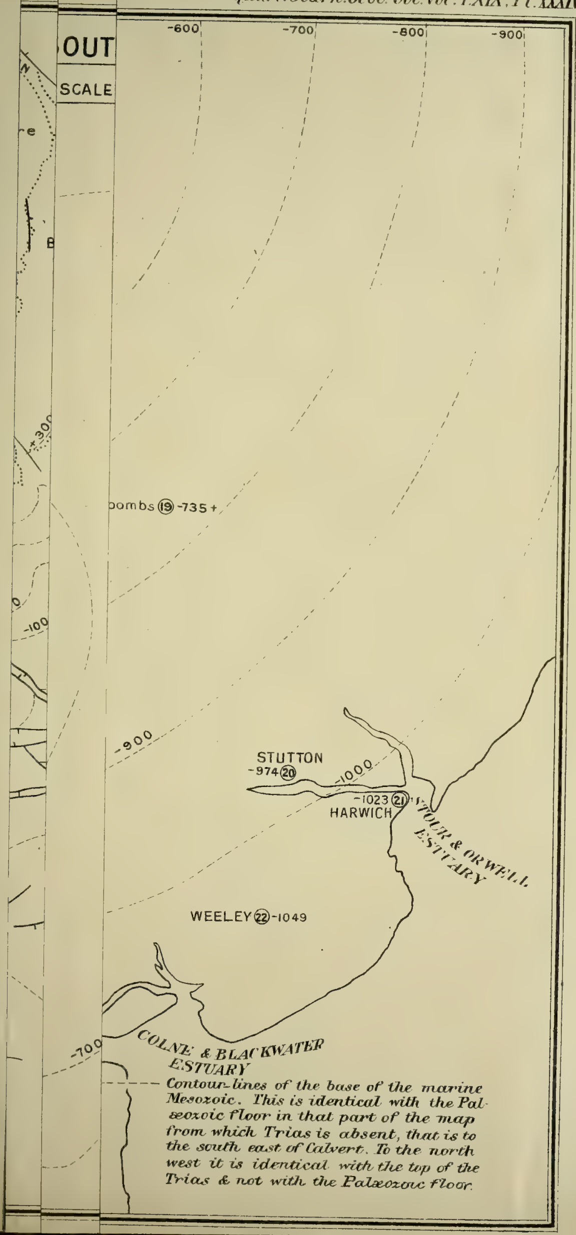
6. × 90

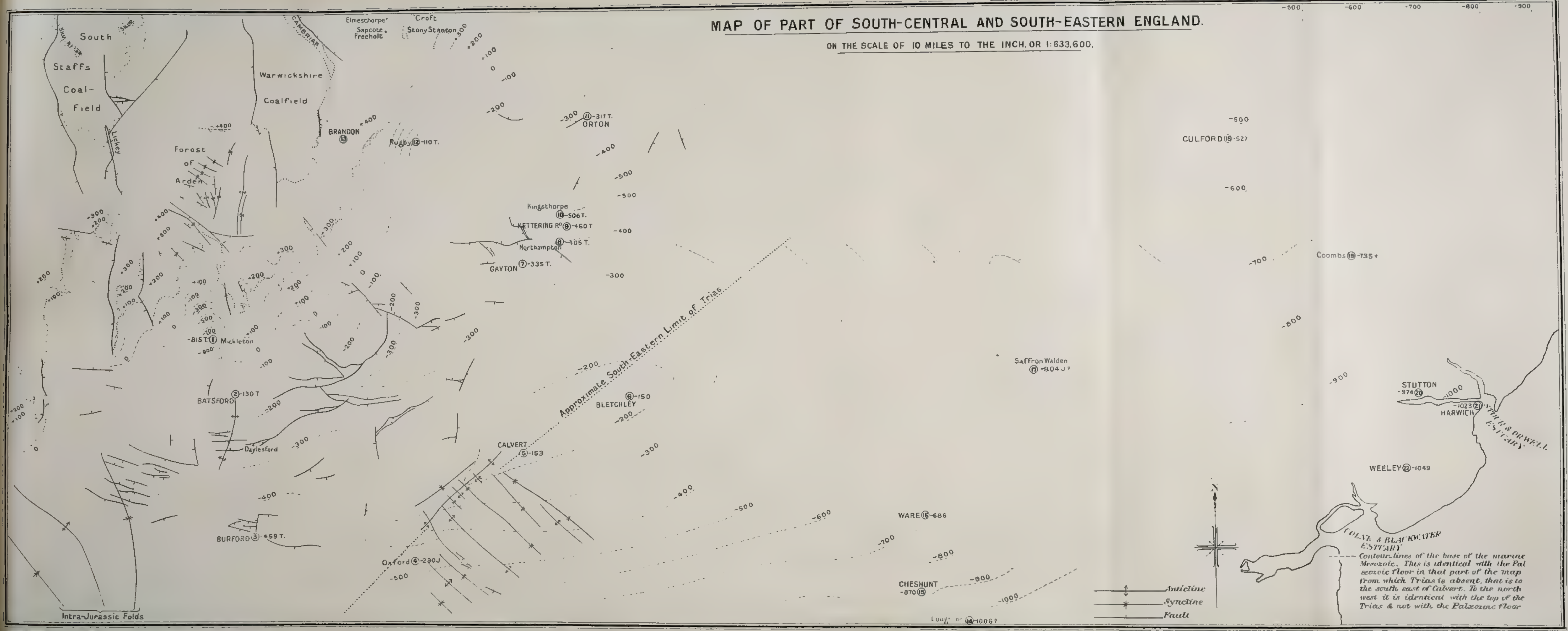


H.G.S., Photo.

Bemrose, Collo., Derby.

ROCKS FROM THE CALVERT BORINGS.


OUT
SCALE
-600
-700
-800
-900
+300
-100
-900
-1000
-700
combs (19) -735 +
STUTTON
-974 (20)
-1023 (21)
HARWICH
STOUR & ORWELL ESTUARY
WEELEY (22) -1049
COLNE & BLACKWATER ESTUARY
Contour-lines of the base of the marine Mesozoic. This is identical with the Palæozoic floor in that part of the map from which Trias is absent, that is to the south east of Calvert. To the north west it is identical with the top of the Trias & not with the Palæozoic floor.


MAP OF PART OF SOUTH-CENTRAL AND SOUTH-EASTERN ENGLAND.
ON THE SCALE OF 10 MILES TO THE INCH, OR 1:633,600.
South Staffs Coal-Field
Warwickshire Coalfield
CAMBRIAN
Elmesthorpe
Croft
Sapcote
Freeholt
Stony Stanton
Forest of Arden
Lickey
BRANDON ⑬
Rugby ⑫ -110 T.
⑪ -317 T. ORTON
Kingsthorpe
⑩ -506 T.
KETTERING Rᴰ ⑨ -460 T
Northampton ⑧ -305 T.
GAYTON ⑦ -335 T.
-815 T. ① Mickleton
BATSFORD ② -130 T
Daylesford
BURFORD ③ -459 T.
Oxford ④ -230 J
CALVERT ⑤ -153
BLETCHLEY ⑥ -150
Approximate South-Eastern Limit of Trias
CULFORD ⑱ -527
Coombs ⑲ -735 +
Saffron Walden ⑰ -804 J ?
WARE ⑯ -686
CHESHUNT -870 ⑮
Loug ⑭ -1006 ?
STUTTON -974 ⑳
-1023 ㉑ HARWICH
STOUR & ORWELL ESTUARY
WEELEY ㉒ -1049
COLNE & BLACKWATER ESTUARY
N
Anticline
Syncline
Fault
Contour-lines of the base of the marine Mesozoic. This is identical with the Palaeozoic floor in that part of the map from which Trias is absent, that is to the south east of Calvert. To the north west it is identical with the top of the Trias & not with the Palaeozoic floor
Intra-Jurassic Folds

Discussion.

The Secretary read the following letter, received from Mr. S. S. Buckman:—

'The discovery that at Calvert the *ornatum* zone rests directly upon Forest Marble is very interesting, because immediately south of Calvert the road to Edgcot passes over a knoll of Cornbrash, which forms a conspicuous feature with a steep hill overlooking the village of Edgcot. There must be a considerable area of Cornbrash here, and the characteristic rock with brachiopods is exposed by the roadside north of Edgcot; but this inlier of Cornbrash is not marked on the Geological Survey map. It is the eastern extension of the line of inliers of Cornbrash which extends from Islip to Ambrosden and to Marsh Gibbon.

'The Cornbrash of Edgcot must be about 100 feet above the base of the *Ornatus* Clays of Calvert, and so there must be a fault to that extent just south of Calvert Station.

'It is interesting to note that beds missing on the downthrow side of a fault are preserved on the upthrow side. The case is exactly parallel with that of the Peak Fault in Yorkshire. The explanation would seem to be that the original axis of the anticlines lay to the north, and that the denudation of the anticlinal folds—in the Calvert case pre-*ornatum*, in the Peak case pre-*murchisonæ*—was accomplished long before the present fault-lines were developed.'

Mr. G. Barrow drew attention to the persistence of the bright green clays in the Forest Marble Group, and asked whether the Authors had ascertained if these clays had been met with in the deep borings under London.

Mr. L. J. Wills enquired of the Authors the distance between the two boreholes, in view of its bearing on the possibility of the occurrence of Trias, as suggested by them, in the western one.

Dr. J. V. Elsden commented upon the description of the absence of Kellaways Rock and Cornbrash in the borehole as a non-sequence, and asked what this term implied. Did it mean non-deposition, contemporaneous erosion, overlap, or what? With regard to the Bletchley Boring, the speaker believed that Charnian rocks occurred here immediately below the Mesozoic, the thick Shineton Shales shown at Calvert being apparently absent, and he asked whether the paper threw any light upon this question.

Dr. C. A. Matley alluded to the great interest of the discovery of Cambrian rocks in the boring, and the close lithological resemblance of these Tremadoc shales with those of Shineton, Malvern, and Merivale. The compound oolitic grains in the Jurassic limestones shown in the lantern-slides exhibited, reminded him of those from the (pre-Cambrian) Cemaes limestones of Anglesey, described and figured by the late J. F. Blake in the British Association Report for 1888. They seemed to the speaker to yield no proof of contemporaneous erosion, but to be recently-formed grains which had become agglutinated as they were moved about by marine currents, and then coated by further layers of carbonate of lime.

Mr. W. H. Booth asked whether the Authors had obtained any

measurement of the general direction of dip which, if of no immediate use, might be of value in connexion with future observations of a similar nature. Dip-observations taken in a stratum several hundred feet thick would surely escape some of the worst effects of mere local dip and folding.

He also suggested some regularly organized system of keeping notes of, at least, all special or deep boreholes, urging the need for educating the workmen in the importance of accuracy.

The President (Dr. A. Strahan) said that he had watched this boring, almost from its commencement, with great interest. He reminded the Fellows that a report that coal had been found in it had been widely circulated; but that the discovery of *Clonograptus* in the supposed Coal Measures had led to a reconsideration of the evidence on which the report was founded. It was most satisfactory that, by combining the information obtained by Dr. Davies with that obtained by Mr. Pringle, acting for the Geological Survey, a reliable account of the strata had been produced.

The question of registration of boreholes, mentioned by a previous speaker, was one to which he hoped to call attention shortly. The recommendation made by the Royal Commission on Coal-Supplies had so far led to no practical result.

Mr. J. Pringle said that the conspicuously green clay which occurred in the Forest Marble at Blackthorn Hill had proved recognizable in the Calvert Boring, and had served as a trustworthy index. He had to thank Mr. Barrow for calling his attention to its importance. He also thanked the Fellows for the cordial reception which they had given to the paper.

Dr. A. M. Davies, in reply, said that Mr. Buckman's contribution was of the greatest importance, and might lead to modifications of view as to the tectonic structure. He replied to Dr. Matley that he had considered the possibility of some of the structures shown by the oolitic rocks being due to contemporaneous erosion rather than to derivation from older rocks, and had decided that this could not be so in all cases, though it might in some. To Mr. Booth he replied that Mr. Hiorns had endeavoured to ascertain the direction of dip; but the preliminary experiments carried out in order to determine the possible deviation of the borehole had been unsuccessful. He considered that the time had not yet come for attempting to make a geological map of the Palæozoic floor.

17. The Geological History *of the* Malay Peninsula.

By John Brooke Scrivenor, M.A., F.G.S., Geologist to the Government of the Federated Malay States. (Read January 8th, 1913.)

[Plate XXXV—Map.]

Contents.

I. Introduction.

Since 1903 a few papers have been communicated by me to this Society and to the 'Geological Magazine' on special points of interest that have been encountered during field-work in the Malay Peninsula, and a number of local publications have appeared in the Federated Malay States, either in the Government Gazettes or as pamphlets issued by the Government Printing Department.[1] These

[1] (1) 'Note on the Sedimentary Rocks of Singapore' Geol. Mag. dec. 5, vol. v (1908) pp. 289–91.
(2) 'Note on the Igneous Rocks of Singapore, &c.' *Ibid.* vol. vi (1909) pp. 17–22.
(3) 'Obsidianites in the Malay Peninsula' *Ibid.* pp. 411–13.
(4) 'Radiolaria-bearing Rocks in the East Indies' *Ibid.* vol. ix (1912) pp. 241–48.
(5) 'The Lahat "Pipe"... in Perak' Q. J. G. S. vol. lxv (1909) pp. 382–89.
(6) 'The Tourmaline-Corundum Rocks of Kinta' *Ibid.* vol. lxvi (1910) pp. 435–49.
(7) 'The Rocks of Pulau Ubin & Pulau Nanas' *Ibid.* pp. 420–34.
(8) 'The Gopeng Beds of Kinta' *Ibid.* vol. lxviii (1912) pp. 140–63.
Among the local publications are the following:—
(9) 'The Geology & Mining Industries of Ulu Pahang,' with a geological sketch-map. Kuala Lumpur, Government Press. 1911.
(10) 'The Geology & Mining Industry of the Kinta District, Perak,' with a geological sketch-map. Kuala Lumpur, Government Press. 1913.

local publications deal with restricted areas, and are, moreover, difficult of access to those who wish to study the geology of the Peninsula. I think, therefore, that an attempt to communicate to the Society in a connected form such evidence as has been obtained since 1903 of the geological history of the Peninsula, but without going into much detail, will not be out of place.

The nature of the work carried on since 1903 has been economic; but, as is well known to field-geologists, it is impossible when engaged on such work to close one's eyes to a mass of interesting information that may have no direct economic bearing, and it is this information that is now presented. It is necessary to add that I make no claim to have completed a survey of the whole Peninsula; in fact, detailed geological surveying has been finished in two portions of the Peninsula only: namely, Ulu Pahang and the Kinta District of Perak, while Mr. William Richard Jones commenced the detailed survey of Selangor this year. Nevertheless, sufficient evidence has been gained in the last nine years to give a very fair idea of the outline of the geological history of the Peninsula.

It is not proposed to enter here into any lengthy discussion of the previous literature dealing with the Malay Peninsula. I have mentioned it elsewhere (Nos. 9 & 10 in the bibliographical list on p. 343). The most remarkable point about it is the almost complete unanimity with which mining engineers and others have given the sequence of the rocks in an inverted order. I must, however, express my gratitude here for valuable assistance in the form of publications on palæontological subjects, to be mentioned later, by Mr. R. B. Newton and the late Prof. T. R. Jones; and also for examination of palæontological material by Dr. A. S. Woodward, Mr. G. C. Crick, Dr. G. J. Hinde, and Mr. H. N. Ridley.

Of literature dealing with countries adjacent to the Malay Peninsula, and that one has to consider in connexion with the geology of the Peninsula, there is much that is of the greatest interest. Some of this—such as the publications of the Geological Survey of India and the 'Manual of the Geology of India'—is well known; but I would especially emphasize the value of the little-known though beautifully-executed geological maps of parts of the Dutch East Indies, the result of the work of Dutch geologists, whose memoirs are to be found in the scientific parts of the Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië. The most important publications, apart from this annual, are the results of Prof. Molengraaff's explorations in Central Borneo [1] and Messrs. Verbeek's & Fennema's 'Geology of Java & Madura.' It is unnecessary to give a complete list here of the literature published by workers in the Dutch East Indies bearing on the geology of the Peninsula.

[1] 'Geological Explorations in Central Borneo' English revised edition, London, 1902.

II. Present Configuration.

The Malay Peninsula and the Malay Archipelago form together a very interesting portion of the earth. To quote Prof. Suess[1]:—

'We have now arrived at one of the most instructive parts of the earth's surface. Four elements combine to form it: the end of the Burman arc, the southern branches of the virgation of the Philippines, the spurs of the great cordillera of New Guinea, and, finally, the continent of Australia with the cordillera which marks its eastern border and crosses Torres Strait.'

Of the Malay Peninsula itself, Suess says (*op. cit.* p. 231):—

'Fresh coulisses make their appearance in the south, and form the Malay Peninsula.... In this way the mighty swell of the Altaides in Thibet subsides and is dispersed. The whole continent becomes lower. Many coulisses disappear. Only a few long branches are continued: on the east into the cordillera of Annam; on the west, always giving rise to fresh coulisses, through the Malay Peninsula, and still further, to Java and beyond.'

Again (*op. cit.* p. 233):—

'East of this [Bandon] valley rises the second granite coulisse, likewise tin-bearing. It emerges from the sea in the island of Koh Tau.... forms the hilly islands, Koh Pungum and Koh Samul..., and entering the Peninsula becomes the Lakawn range, which thence onwards represents the axis of the Peninsula. Still further south this long granite range breaks up into isolated ridges and, associated with ancient sediments, reaches the sea near Singapore. A series of cliffs and smaller islands reveals its continuity with the tin-producing islands of Banka and Billiton.'

Unfortunately, the material on which Prof. Suess's description is based is somewhat out of date, and consequently it is impossible to agree with every point of it. I have dealt with the question of the 'ancient sediments' elsewhere, in connexion with another publication.[2] There is good reason to believe that the Lakawn (or Nakawn) Range is distinct from the axis of the Peninsula; and the 'long granite range' that forms this axis can hardly be described as reaching the sea near Singapore.

The accompanying sketch-map (Pl. XXXV) shows diagrammatically the chief structural features of the Peninsula; and, although the States of Johore, Kelantan, Trengganu, and the country between Kelantan and Singgora are of necessity left almost entirely blank for want of information, it will be seen that the greater part of the Peninsula has been covered.

Near the top of the map a range of hills will be seen trending northwards from near Alor Star to Singgora. This range, which has no distinctive name so far as I am aware, may be conveniently referred to as the Kedah-Singgora Range. West of it the country is low-lying and traversed by an earth road, by which one may travel from Alor Star to the China Sea. This Kedah-Singgora Range, composed of quartzite and shale, may be regarded as a barrier cutting off the Peninsula proper from the Isthmus, and it is to the east of this range that the great main granitic axis of the

[1] 'The Face of the Earth' vol. iii (1908) pp. 231–32, English translation.
[2] Geol. Mag. dec. 5, vol. vi (1909) pp. 330–32.

Peninsula and its branches have their origin. The Kedah-Singgora Range consists of hills of no great altitude. Exact measurements, I believe, have not been made; I doubt whether any of the summits reach 1000 or even 800 feet above sea-level.

The beginning of the main granitic axis is shown on the sketch-map (Pl. XXXV), and the range is traced between Kelantan and Perak, Pahang and Selangor, into Negri Sembilan, where it breaks up into smaller ranges. This granitic axis will be referred to as the Main Range.

In the north the Main Range is as yet imperfectly known. I have marked it on the map as though it were a broad granite-outcrop; but my own notes in Upper Perak prove that the granite is associated with other rocks, such as crystalline limestone and wollastonite-schist. The sketch-map must not, therefore, be taken as indicating in this part of the Peninsula one unbroken granite-outcrop, but rather as showing the area over which granitic outcrops form important structural features.

Branching off from the Main Range near its commencement are granitic outcrops that end in the granite of Penang. These outcrops form hills in Southern Kedah and in Province Wellesley. They are not connected one with the other, so as to form an unbroken chain of mountains. Kedah Peak is another granite-mass.

In the upper waters of the Krian River the granite of the Main Range forms great mountains, behind which are other granitic peaks in the north of Perak. One well-defined spur, however, comes down in a south-south-westerly direction, forming the eastern boundary of the Larut District and ending in the granitic hills of the Dindings.

Another spur is given off from the Main Range between the Perak and Kinta Rivers, known as the Kledang Range.

In the south of Kinta the Bujang-Malaka granite-mass marks a westward protrusion of the granite of the Main Range; and there is some evidence that this granite-mass may be connected with the granite of the southern part of the Kledang Range, at no great depth from the surface.

Another protrusion of granite from the Main Range juts out towards the centre of Selangor. The hills formed by this mass end at Rawang, but small intrusions of granite are known on the west, and an isolated granitic hill occurs at Kuala Selangor.

Intrusions of granitic rocks are known on the coast of Negri Sembilan and Malacca. These may be regarded as the last outcrops of the granite of the Main Range.

Another isolated granite-hill is found at Jugra in Selangor. Its relation to the Main Range is at present unknown.

Returning to Perak, we find between Krian and Larut an isolated range of quartzite, conglomerate, and shale, the Semanggol Range; and quartzite-hills are found near Telok Anson. In Selangor such hills form a large part of the State.

On the east of the Main Range, I have little first-hand information from Kelantan, but the hills in the large State of Pahang

are well known to me. At the foot of the Main Range is a chain of quartzite-, conglomerate-, and shale-hills that I have called elsewhere the 'Main Range Foothills.' These are almost certainly continued northwards into Kelantan, and enter Negri Sembilan in the south.

Travelling eastwards from these Main Range Foothills, one encounters a huge isolated range of hills, the Benom Range, composed of mica-granite, hornblende-granite, and syenitic rocks. Small granitic outcrops on the River Tanun mark the dying away of this range to the north; and on the south similar outcrops are found extending into Negri Sembilan. Mount Ophir, in Johore, near the Malacca border, may prove to be a southern prolongation of the Benom granite.

Eastward again from the Benom Range and to the east of the Pahang River is a great belt of hilly country, composed of quartzite, conglomerate, and shale, that extends northwards into Kelantan and southwards into the Rumpin District. The trend of the hills points directly to Singapore, where similar rocks are exposed; and it is believed that these Singapore quartzites, etc., and the Pahang quartzites are connected by outcrops in Johore. It is impossible to speak more definitely at present on this point, but a traverse along the greater part of the Johore Railway left little doubt as to what may be expected when further research can be undertaken in that part of the Peninsula.

This belt of hills east of the Pahang River may be described conveniently as the 'Main Gondwana Outcrop,' for reasons that will be given later. It is for the most part composed of hills of no great altitude: in the north of Pahang and the south of Kelantan, however, the outcrop is bounded on the west by the Tahan Range, composed of the same rocks, but containing the highest peak in the whole Peninsula, Gunong Tahan. (Gunong Tahan is 7188 feet above sea-level; Gunong Riam, or Kerbau, the highest peak in the Main Range, 7160 feet; Gunong Benom, in the Benom Range, 6916 feet.)

East of the Main Gondwana Outcrop in Pahang and Kemaman are more granitic ranges; and the island of Tiuman in the China Sea is built up of granite, with some highly-altered sedimentary rocks.

Apart from these granitic and quartzitic ranges, there are in the Peninsula numerous limestone-hills with precipitous sides that afford most interesting evidence of the past history of this part of the world. They are not marked on the map, except Gunong Geriang in Kedah; and it is sufficient to say that the greatest development of them is found in the Kinta district of Perak. There are several limestone-hills in Pahang, some being of great size.

The western coast of the Peninsula is mostly low-lying mangrove-swamp, extending in some parts for many miles inland and broken by occasional sandy beaches, isolated granite-hills, and small isolated quartzite-hills. Much of this low-lying tract has been reclaimed, and furnishes very fine agricultural land.

The eastern coast also is low-lying, but more sandy than the west, and from it, too, isolated hills spring up like islands.

In the Straits of Malacca there are a few rocky islands, distinct from the large mangrove-covered islands such as those that fringe parts of the coast of Perak and Selangor. In the China Sea numerous rocky islands, of which Tiuman is the largest, lie close to the coast.

III. Brief Sketch of the Geology of the Peninsula.

Anyone who has read some of the earlier works on the tin-fields of the Peninsula would naturally conclude that the superficial recent deposits are of great importance. This, however, is not the case, owing to the fact that the Peninsula is now experiencing a long-continued period of uplift, which has prevented any great accumulations of alluvium in the valleys. Weathered rocks *in situ*, soft granitic rocks rich in kaolin, and Palæozoic clays have been described erroneously as alluvium, and we can confine our attention almost entirely to the solid geology of the country. A brief sketch of this now will make subsequent sections more easily understood.

The oldest-known rocks *in situ* are a calcareous series, named provisionally the Raub Series, with which is associated in Pahang the Pahang Volcanic Series, partly contemporaneous with the Raub Series, but continuing into later times. The Raub Series forms a large part of the lower-lying land of the Peninsula, where the rivers have cut down to it through superincumbent rocks. A series of radiolarian cherts and fine-textured shales is believed to be a phase of the Raub Series.

Unconformable to the Raub Series is a great development of littoral rocks—quartzite, conglomerate, shale, clay-slates, and phyllites formed by metamorphism of the shales. Some rocks of the Pahang Volcanic Series are contemporaneous with part of them. In the Kinta district of Perak, and in other localities, at the base of these littoral rocks is a considerable thickness (about 200 feet where best preserved) of stanniferous clays with boulders, believed to be of glacial origin. The quartzites, etc. form a large part of the hilly country of the Peninsula, and they, together with the glacial clays, will be referred to collectively as the Gondwana rocks.

Intrusive into the Raub Series and the Gondwana rocks is the granite of the ranges enumerated above, with other associated plutonic rocks.

No granite *in situ* in the Peninsula is known to be older than the Raub Series and the Gondwana rocks; but in the glacial clays, the tuffs of the Pahang Volcanic Series, and the conglomerate of the Gondwana rocks, there is evidence of a much older granite that was stanniferous like the younger granite. The granite that is older than the Raub Series, etc., and not yet known *in situ*, is referred to as the Palæozoic Granite; the younger granite is referred to as the Mesozoic Granite.

Later than the Mesozoic Granite, and unconformable on the Gondwana rocks, are some Coal Measures of Tertiary age which crop out in Selangor. Dykes of dolerite which cut the Mesozoic Granite are believed to be of Tertiary age also.

The only recent deposits that will be dealt with here are deposits of lignite and sand overlying glacial clay and limestone in Kinta, as also some interesting torrential boulder-deposits.

IV. The Raub Series.

The Raub Series is calcareous throughout, but for a few shales that do not effervesce with acids, and is best seen in the valley of the Pahang River and its tributaries. It comprises limestone and shales with a greater or less percentage of lime, and there is reason to suppose that some of the shales contain a certain amount of very fine volcanic ash, which betrays itself by a buff coloration, while the ordinary shales are deep greyish-blue. Some of the shales contain carbon.

The limestones range in colour from white, through grey, to black; occasionally they are reddish. The black limestones contain carbon in quantity. Even in cases where organisms can be easily distinguished, the limestones are to a large extent crystalline.

On the west of the Main Range the limestones are markedly crystalline, and only crinoid-stems and other obscure fossils have been noted.

In the Kinta Valley the limestone is exposed as well as could be desired in the limestone-hills, and in the mines in the floor of the valley. In some places it also rises as smooth-surfaced pinnacles above a thin layer of soil, and in the pinnacles evidence has been found of disturbances on a large scale.

The only point that need be noted here, concerning the alteration of the limestone by the Mesozoic Granite, is the rarity of tourmaline as a product of metamorphism.

V. The Chert Series.

I need not repeat here the description of this series given in the 'Geology & Mining Industries of Ulu Pahang' (pp. 35–37) and in the 'Geological Magazine.'[1] The most important point to notice is that the available evidence shows an unconformity between the Chert Series and the Gondwana rocks.[2]

VI. The Gondwana Rocks.

Apart from the glacial clays, these rocks are best seen in Pahang, where fossils have been found near Kuala Lipis and on the Benta-Kuantan road, but fossils have also been found in Perak and Singapore. At first, these rocks were called provisionally the

[1] 'Radiolaria-bearing Rocks in the East Indies' Geol. Mag. dec. 5, vol. ix (1912) pp. 241–48.

[2] *Ibid.* p. 244.

Tembeling Series. They consist of conglomerate, quartzite, grit, shale, and clay-slate. The two first-named rocks contain pebbles of radiolarian chert. The quartzite is very largely weathered back to sandstone, and the 'Myophorian Sandstone' described by Mr. R. B. Newton belongs to this group.[1]

There is not much to add here to the description of the Malayan glacial deposits given in my paper on the Gopeng Beds. They have been traced northwards and southwards outside the Kinta District, and are now known to cover a large area. There is one important addition to be made, however, and that is a continuation of my remarks (on pp. 157-58 of the paper just mentioned) regarding the relations of the corundum-boulders in the glacial clays on the east side of the Kinta Valley to the tourmaline-corundum rocks found on the west side. Evidence has now been collected, showing that the similarity noted by Mr. W. M. Currie, of the clays containing the tourmaline-corundum rocks with glacial clays, is supported by facts; while my first notion, of the tourmaline-corundum rocks and the containing clay being the remains of much-weathered schists,[2] can no longer be maintained. Now that the survey of Kinta has been completed, it is found that this earlier view involves hopeless difficulties. For instance: if bedding in the clays over the limestone on the east is preserved, why is it not preserved in the clays over the limestone on the west? The limestone is similarly affected by ground-water in both areas, and there is no evidence to show that there has been a greater sinking movement of clays over it in one area than in the other. The inevitable conclusion is that bedding never existed in the western clays, and that they really are, what they seem to be, glacial boulder-clays. This question of the relation of the eastern and western clays is discussed fully in the memoir on the Kinta Valley now in the press.

VII. The Pahang Volcanic Series.

This series of volcanic rocks is widespread in the interior of Pahang, west of the Main Gondwana Outcrop. Only a few occurrences are recorded outside Pahang. It has not been studied very minutely as yet, but enough is known to say that it is composed of lavas and ashes and perhaps of hypabyssal masses. The rocks comprised in the series are quartz-porphyry, porphyry, granophyre, dacite, andesite, augite-andesite, and dolerite. They are frequently sheared and metamorphosed near the granite-junctions. I have already described the alteration of the dacites and dacite-tuffs of Pulau Nanas, near Singapore, by the Mesozoic Granite.[3] The greater part of the eruptions that produced these rocks were submarine.

[1] 'On Marine Triassic Lamellibranchs discovered in the Malay Peninsula' Proc. Malac. Soc. vol. iv, pt. 3 (1900) pp. 130-35.

[2] Q. J. G. S. vol. lxvi (1910) p. 438.

[3] *Ibid.* pp. 427-28.

VIII. The Mesozoic Granite.

All the granitic ranges of the Peninsula are, so far as is known, remnants of approximately contemporaneous intrusions. The available evidence points to the date of intrusion as having been at some time after the Trias and before the Eocene, perhaps between Inferior-Oolite and Cretaceous times.[1] Most of the granite contains large porphyritic felspar-crystals, but some is non-porphyritic. There is no reason to suppose that this difference marks any important distinction with regard to the epoch of intrusion.

The only other point in the petrology of the granite and associated rocks to be noted here, is the fact that the Benom Range differs markedly from other granitic ranges in the Peninsula. In the Main Range, for instance, hornblende occurs sparingly, sometimes in quantity; but, in the Benom Range, the rocks that are known are mostly hornblende-granites and syenites. Ordinary granite is known to occur, however. Porphyritic crystals of felspar are found in the hornblende-granite, as in the granite of the other ranges.

IX. The Tertiary Coal Measures.

The Tertiary Coal Measures were found in Selangor in 1908. The credit of the discovery belongs to a Malay, who was prospecting for tin-ore by means of shallow pits, and found instead a seam of coal that proved later to be 40 feet thick. The Coal Measures were mapped as well as circumstances allowed—they occur in the densest virgin-jungle where there are no large streams, but plenty of swamp—by the difference between the soil formed by the Coal Measures and the soil formed by the quartzite and clay-slate on which they lie. But for an extension into swampy ground, where, of course, geological mapping was impossible, prospecting work by means of bores has shown that the limits of the Coal Measures thus indicated were fairly correct. They cover about 2 square miles, and are a remnant preserved on a low watershed from denudation. The coal is of poor quality, being on the border-line of the coals and lignites; and, if the fixed carbon or calorific value be taken as the basis of classification, it should be termed a 'lignite.' It might equally well be termed 'pitch-coal' or 'sub-bituminous coal.' Some of the shales have been found to contain a small quantity of oil.

A number of fossil leaves have been collected from the shales, which Mr. H. N. Ridley, F.R.S., kindly examined for me. Like the flora of the Borneo Coal Measures, they resemble existing jungle types. The only shells found so far are some crushed specimens that are probably assignable to *Helix*.

The evidence for the Coal Measures being Tertiary is that they are unconformable on the greatly-disturbed quartzite and clay-slates; also that they show no trace of alteration by the granite, intrusions of which, with tin-ore, into the quartzites and clay-slates

[1] See Q. J. G. S. vol. lxvi (1910) p. 429.

occur not far from the Coal Measures. The high percentage of moisture in the coal also (about 20 per cent.) points decidedly to its deposition at a later date than the granite-intrusion and the earth-movements that occurred when the granite was intruded.

Reference to Dr. Th. Posewitz's 'Borneo: its Geology & Mineral Resources' [English transl.] 1892, will show that the plant-remains, although they support the other evidence of Tertiary age, do not help us in determining to what part of the Tertiary Era they should be referred (pp. 201, 224, 225). Van Hooze, however, has based an arrangement of Bornean coals on the percentage of moisture, thus (*op. cit.* pp. 219 & 220):—

Eocene	4 to 6 per cent. of hygroscopic water.		
Oligocene	9 to 14	do.	do
Miocene	19 to 25	do.	do.

The idea of gradual dehydration underlying this arrangement is obvious. The Selangor Coal Measures, on this test alone, would be considered Miocene; nevertheless, the conclusion must be supported by other evidence before it can be accepted as satisfactory.

X. Fixed Geological Horizons in the Malay Peninsula.

Before going farther, it is necessary to discuss what evidence there is of fixed geological horizons in the Peninsula on which a description of its history can be based.

Taking the calcareous Raub Series first, the palæontological evidence is not very satisfactory. Fossils from limestone in Pahang have been referred by Mr. G. C. Crick to *Orthoceras*, *Cyrtoceras*, *Gyroceras*, and *Solenocheilus*. Mr. R. B. Newton wrote to me concerning these limestone fossils:—

'Hence the rocks may be recognized as of Carboniferous age.'

Imperfect casts and impressions of fossils are not uncommon in the weathered calcareous shales, but at one locality only, in Pahang, have any been collected that are of homotaxial value. Concerning these, Mr. Newton wrote:—

'.... The fossils themselves are badly preserved, being little more than impressions, and therefore are not sufficiently defined for illustration and detailed description. The most prominent are those having a circular or elliptical outline, which Mr. G. C. Crick determines as an Ammonoid resembling Waagen's *Xenodiscus*. There are also some straight tube-like organisms which appear to be closely allied to *Dentalium herculeum* of de Koninck. The association of these two fossils is interesting, since similar forms are found together in the Upper *Productus* Limestone of the Salt Range, India, a fact which would favour the Malay specimens being of Permian age.

'There are a number of other organisms, but very much too obscure for determination, among them being an Aviculopectinoid impression and some possible brachiopod remains.

'Both Mr. Crick and I think these fossils younger than those referred to by Prof. Hughes as Permo-Carboniferous, in his notice of specimens from Malaya collected by the "Skeat Expedition" (Rep. Brit. Assoc. Glasgow, 1901, p. 414) on account of the presence of a trilobite determined as *Proetus*.'

With regard to the fossils collected by the Skeat Expedition,

I do not know their exact locality, nor have I seen the rock that contains them. In the report quoted, Prof. McKenny Hughes says that the rock is almost entirely composed of silica, but that there must have been originally much carbonate of lime.

We see, then, that the few fossils found point to the Carboniferous age of certain limestones and the Permian age of certain shales. But the field-evidence in favour of the limestones and shales belonging to one series is so strong, that we cannot accept the palæontological evidence without qualification. The fossils found so far, in fact, have done no more than give a hint as to the age of the rocks: they may be Carboniferous or Permo-Carboniferous. Other evidence, unknown at the time when the fossils were described, make it improbable that they are Permian.

It is interesting to note that, in Sumatra, Dr. Verbeek has described *Fusulina* limestone that is Carboniferous, as well as 'Culm.'[1] Wing Easton[2] also described 'Culm' and Carboniferous Limestone in the Toba District. Prof. Rothpletz[3] describes at length fossils from Permian rocks in Timor and Rotti.

In Indo-China, pale-grey Permo-Carboniferous limestone is found in Upper Tongking,[4] and Upper Carboniferous and Lower Permian deposits in Tongking.[5] M. N. Mansuy, again, describes fossils from Permo-Carboniferous limestones in Indo-China.[6]

There is no horizon in the Raub Series, then, that we can regard as fixed; but immediately above this series, in Perak, come the glacial clays, which furnish a more valuable horizon on climatic evidence than can be afforded by limited collections of fossils in rocks far removed from Europe. It is but reasonable to suppose that the great climatic change that took place towards the close of the Palæozoic Era affected what is now India, South Africa, and Australia simultaneously, as geological time is measured.[7] The Malayan glacial beds, then, may be correlated with the glacial beds at the base of the Salt-Range *Productus* Beds, with the Talchir Group at the base of the Gondwana Series, and with the Australian and South African glacial deposits. For purposes of correlation with deposits in these countries the Malayan glacial clays can be regarded as a fixed horizon; but, when we come to consider how they

[1] R. D. M. Verbeek, 'Topographische & Geologische Beschrijving van een Gedeelte van Sumatra's Westkust' Batavia, 1883, pp. 29, 240–47, 247–67.

[2] N. Wing Easton, 'Een Geologische Verkenning in de Toba-Landen' Jaarb. Mijnw. Nederl. O.-I. vol. xxiii (1894) Wetensch.-Gedeelte, pp. 126–28.

[3] A. Rothpletz, 'Die Perm-Trias & Jura-Formation auf Timor & Rotti im Indischen Archipel' *Ibid.* pp. 12–62.

[4] G. Zeil, 'Contribution à l'Étude géologique du Haut Tonkin' Mém. Soc. Géol. France, ser. 4, vol. i, No. 3 (1907).

[5] H. Lantenois, 'Note sur la Géologie de l'Indo-Chine' *Op. cit.* No. 4.

[6] 'Contribution à la Carte géologique de l'Indo-Chine: Paléontologie, 1908' Imprimerie d'Extrême Orient, Hanoi-Haiphong.

[7] I am aware that Mr. S. H. Ball & Mr. M. K. Shaler have described a 'Central African Glacier of Triassic Age' Journ. Geol. Chicago, vol. xviii (1910) pp. 681–701, and have noted the very scanty evidence on which their determination of age is based.

are to be described with regard to the European geological sequence, we find that the matter is not so simple as one might imagine. This can be illustrated by extracts from the 'Manual of the Geology of India' 2nd ed. (1893). On p. 121 it is stated that fossils from the beds above the boulder-clay of the Salt Range show that they are approximately contemporaneous with the marine Carboniferous of New South Wales, and that these Australian beds were formerly regarded as equivalent to the Lower Carboniferous of the European sequence, but are now considered as Upper Carboniferous, if not homotaxial with the Permo-Carboniferous of Europe. On p. 125 we read of the uppermost division of the Lower *Productus* Beds:—

> 'This fixes the homotaxis of these beds as Upper Carboniferous, or intermediate between that and Permian.'

On p. 127 we read of the Middle *Productus* Beds:—

> 'These Mesozoic forms preclude us from assigning the group to an older date than the Permian';

but the plate facing p. 126 has the legend 'Permo-Carboniferous (Middle *Productus* Limestone) fossils.'[1]

The Talchir Boulder-Bed (p. 208) is referred to the Upper Carboniferous, and is regarded as belonging to the same horizon as the boulder-bed of the Salt Range; but on p. 207 we also read that

> 'the suggestion made by Mr. H. F. Blanford in 1875, that the Talchir Boulder-Bed was contemporaneous with the Permian glacial deposits of England, has never been absolutely disproved, and as recent investigations have shown that the supposed Lower Carboniferous deposits of Australia are newer than they were formerly considered to be, it is still possible that this may be the true equivalence.'

Then the base of the *Productus* Beds may be Permian also?

The glaciation may, therefore, have occurred at any time from the Upper Carboniferous to the Permian. The extracts concerning the *Productus* Beds alone, given above, show that the glaciation may have been at least as late as the Permo-Carboniferous. In Sir Archibald Geikie's 'Textbook of Geology' occurs the following passage, illustrating this doubt as to the date of the late Palæozoic glaciation:—

> 'The evidence now accumulated from South Africa, India, Cashmere, and Australia, seems to point to some general operation on a gigantic scale in the southern hemisphere at the close of the Carboniferous or in the Permian Period.' (4th ed. vol. ii, 1903, p. 1060.)

This is interesting and important, in connexion with the Malayan glacial deposits and the underlying Raub Series. If the glacial beds were assumed to be Upper Carboniferous, with no alternative—then the palæontological evidence which points to the

[1] Dr. E. W. Vredenburg, in his 'Summary of the Geology of India' (1907), gives on p. 42 the following classification of the *Productus* Beds:—

Lower *Productus* and lower part of the Middle *Productus* Beds = Upper Carboniferous.

Remainder of *Productus* Limestones = Lower Permian (Permo-Carboniferous or Artinskian).

Raub Series being either Carboniferous or Permian, or Permo-Carboniferous, would be a serious difficulty. If, however, one remembers that the glacial beds may be as late as Permian, then the difficulty disappears; and the Raub Series can be regarded as older than the *Productus* Beds, unless it is in part equivalent to the shales underlying the boulder-beds in the trans-Indus section of the Salt Range.[1] This climatic horizon may, therefore, be referred to the similar horizons in India, South Africa, and Australia; but, in general terms, we can only say that its age may be anything from the Upper Carboniferous to the Permian, more probably nearer the latter.

The glacial clays are regarded as the base of the Malayan Gondwana rocks, just as the Talchir glacial deposits are the base of the Indian Gondwana Series, and I must now justify my use of the term 'Malayan Gondwana rocks.' The Myophorian Sandstone is marine, but the rocks with which it is associated and the absence of interbedded limestones show that it was deposited close to the shore. The fossils found in the extension of the rocks in Singapore are also marine,[2] but for *Podozamites* and a seed referred to *Carpolithes*. The occurrence of the former of these plants led Mr. Newton to suggest that these rocks are an outlier or extension of the Upper Gondwanas of India.[3] In Perak a phyllopod has been collected from shales associated with the typical conglomerate, described as *Estheriella radiata*, var. *multilineata*,[4] which may have been incorporated in the rock under marine conditions, although the living *Estheriæ* are confined to fresh or rarely brackish water. Nicholson & Lydekker say[5] that fossil *Estheriæ* not uncommonly occur in conjunction with undoubted marine remains, but that they appear, on the whole, to occur most frequently in those accumulations that

'have been decidedly the result of brackish-water inundations and of more permanent lagoons (Jones).'

No other fossils of homotaxial value, other than those collected in Pahang, Perak, and Singapore, have been discovered as yet in these rocks; but the evidence afforded by those that have been collected, coupled with the climatic evidence of the Gopeng Beds, seems to me sufficient for the belief that we have here an extension of the Gondwana System of India. It is not claimed that the circumstances of the formation of the Malayan rocks were identical with those under which the mass of the Gondwana System was laid down. That is clearly impossible, seeing that, although there is

[1] 'Manual of the Geology of India' 2nd ed. (1893) p. 120.

[2] See R. B. Newton, 'Notice of some Fossils from Singapore, &c.' Geol. Mag. dec. 5, vol. iii (1906) pp. 487–96 & pl. xxv.

[3] *Op. cit.* p. 488.

[4] R. B. Newton, 'Note on the Age & Locality of the *Estheriella* Shales from the Malay Peninsula'; also T. R. Jones, 'Note on a Triassic *Estheriella* from the Malay Peninsula' Geol. Mag. dec. 5, vol. ii (1905) pp. 49–52 & pl. ii.

[5] 'Manual of Palæontology' vol. i (1889) p. 511.

some petrological similarity, the Malayan rocks have yielded many distinctly marine forms; while the bulk of the Gondwana deposits of India have yielded land-forms only (plants, amphibia, and reptiles). The occurrence of *Estheriella*, however, is suggestive, as *Estheriæ* are found in the typical Gondwana rocks of India,[1] sometimes with remains of plants, amphibia, reptiles, and fishes. Nevertheless, no such remains have been found with the Perak *Estheriella* as yet; and there is not sufficient reason to suppose that in any part of the Malayan Gondwanas the mode of deposition was identical with that of the bulk of the Indian Gondwana System. The Malayan rocks appear to have been deposited under much the same circumstances as the Ragavarum, Tripetty, Vemavarum, and Sripermatúr Beds of the Gondwana System on the eastern coast of India, in which marine organisms occur together with plant-remains.[2]

At the base of the Malayan Gondwana rocks is a climatic horizon that we can regard as fixed. Is there any other horizon in these rocks that can be regarded as fixed? The presence of *Estheriella* in Perak points to the Trias. Mr. Newton says of the beds containing the Singapore fossils that they

'may be of Middle Jurassic age, and about the horizon of the Inferior Oolite of England.' (Geol. Mag. dec. 5, vol. iii, 1906, p. 488.)

The Myophorian Sandstone of Pahang Mr. Newton referred to the Rhætic, because of the presence of *Chlamys valoniensis*. Miss M. Healey, who has described the Napeng Beds of Upper Burma as Rhætic, supports Mr. Newton in his views as to the age of the Myophorian Sandstone.[3] There seems, then, to be a strong case for the existence of a definite Rhætic horizon in the Peninsula. Let us see how this works in with the other evidence. Taking the Malayan glacial beds as equivalent to the Talchir Group of Orissa, then the Myophorian Sandstone would be the equivalent of the Mahádeva Group, or possibly the Pánchet Group of the Indian Gondwanas.[4] The Singapore fossils, however, were found almost directly on the line of strike of the Myophorian Sandstone, and it seems probable that we shall have to take full advantage of the doubt expressed by Mr. Newton as to the age of these Singapore rocks, in order to reconcile the facts. Apart from this, there is the further difficulty of fitting in the comparatively small outcrops of the Malayan Gondwanas, as a whole, into their places in the great thickness of the Indian sequence. The Mahádeva Group is stated to be 10,000 feet thick, the Pánchet Group 1800 feet. The Myophorian Sandstone as exposed on the Benta-Kuantan road in Pahang is 10 feet thick. But the Malayan Gondwanas are littoral deposits; and, if we imagine the Gondwana coast-line in these parts to have been slowly advancing eastwards, perhaps with many checks and oscillations, then the evidence becomes more intelligible. This hypothesis:

[1] 'Manual of the Geology of India' 2nd ed. (1893) pp. 170, 171, 185.

[2] *Ibid.* p. 180, &c.

[3] 'The Fauna of the Napeng Beds or the Rhætic Beds of Upper Burma' Pal. Indica, n. s. vol. ii (1908) Mem. 4, p. 2 (Mem. Geol. Surv. India).

[4] 'Manual of the Geology of India' 2nd ed. (1893) p. 208.

namely, that of the Gondwana coast-line advancing from west to east, has been adopted, in order to explain the occurrence of the glacial rocks in Perak and the Rhætic horizon in Pahang. It will be interesting to see how far future work supports it.

XI. The Growth of the Malay Peninsula.

Starting from the late Palæozoic climatic horizon given by the glacial rocks, one can now form some idea of the history of this part of the globe. The time was that which saw the beginning of the *Productus* deposits of the Salt Range and the beginning of the Gondwana System in Peninsular India. Prior to the advent of glacial conditions, the site of the Malay Peninsula had been covered by a sea in which calcareous deposits (the Raub Series) were being laid down. These may have been in part time-equivalents of the beds which underlie the boulder-beds in the trans-Indus section of the Salt Range. But for this possibility they must be regarded as older than the *Productus* Beds. Submarine eruptions had occurred over part of the floor of this sea, and were continued into later times.

The advent of glacial conditions coincided with the advance of the coast-line of Gondwanaland to the site of the Malay Peninsula. The constitution of the glacial deposits gives some idea of the surface of this portion of Gondwanaland. It was partly formed of stanniferous granitic rocks (the Palæozoic Granite), tourmaline-granite being common, and of rocks metamorphosed by the Palæozoic granite-magma. Some of the rocks forming this part of Gondwanaland evidently held quantities of corundum, both as pure massive corundum (now found as boulders), and as granular corundum in the tourmaline-corundum rocks of Kinta.

The glacial deposits were succeeded by the littoral Malayan Gondwana rocks, deposited as the coast-line moved slowly eastwards until, at the least, Rhætic times were reached.

Then the record is broken, until the intrusion of the Mesozoic Granite in late Mesozoic times; and the intrusion of this granite was made possible by earth-movements which gave rise to the present main structural features of the Peninsula.

Most of the literature dealing with the Peninsula mentions the great granitic axis, and it would not be surprising to find that this axis is regarded as the dominant structural feature. The key to the structure, however, is found, not in any granitic range, but in the Main Range Foothills of Pahang, built up of Gondwana rocks. This range of foothills is composed of the eastern limb of one great anticline and the western limb of another. The one is the Main Range Anticline, the other the Benom Anticline, and they are the framework of the Peninsula: although it is evident that, on both sides of the country, less notable disturbances have admitted smaller granite-intrusions.

The Main Range Anticline has been studied in detail in Perak and Pahang. It should strictly be described as a shattered anticlinorium,

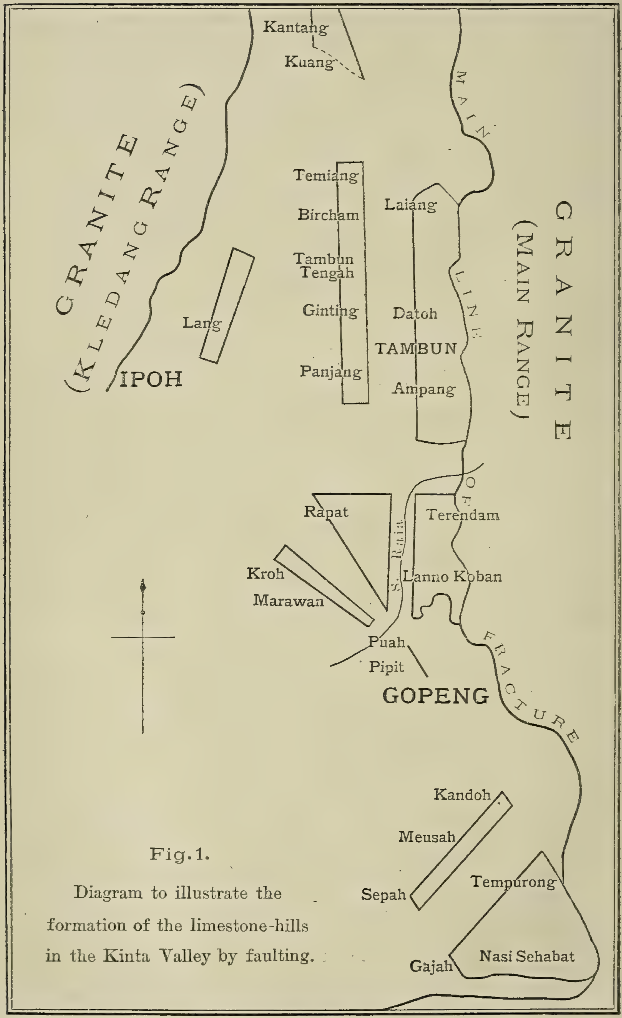


Fig. 1.

Diagram to illustrate the formation of the limestone-hills in the Kinta Valley by faulting.

and in the Kinta district of Perak one observes striking evidence of the magnitude of the faulting that accompanied the earth-movements. This is shown diagrammatically in fig. 1 (p. 358). The shaded areas represent those groups of limestone-hills, the cliffs of which are known by field-evidence to be for the most part fault-faces. On the east it will be noticed that three groups of hills abut on the granite; and in each group there is evidence that the line of the granite-junction is a line of fracture,[1] the downthrow side being occupied by the granite, into which the limestone and Gondwana rocks sank bodily before the magma solidified, except for some quartzite and phyllites found at the summit of Gunong Riam (or Kerbau), which are the remains of the Gondwana rocks, or of rocks younger still, floating on the very highest part of the range.[2] The groups of limestone-hills are portions of the Raub Series which sank on to the magma relatively less than the rocks that form the floor of the Kinta river-valley, or which were raised relatively higher while the granite welled up. The arrangement of the groups is interesting, as showing the trend of the lines of stress. The main line of fracture, on the east, takes a right-angled turn at the bottom of the diagram. From the corner of this angle the granite-border trends to the west of north, and a marked, but interrupted, line of fracture in the limestone-hills runs through Tempurong and Kandoh, and through the small hills north of Gopeng to Rapat, parallel to the granite-border. Near Gopeng the granite-border turns northwards, and the lines of the limestone-cliffs north of Puah and Pipit show other lines of weakness parallel to the main fracture; but in the Kroh-Marawan Group there is evidence of other fractures radiating from Puah and Pipit. The Lang Group, near Ipoh, is roughly parallel to the border of the granite of the Kledang Range on the west side of the valley. This range, as may be seen from the sketch-map (Pl. XXXV), is a spur coming off from the Main Range; and it marks a small subsidiary fold in the crust, connected in the north with the Main Range Anticline. Subtending the angle at the bottom of the diagram are, as we might expect, other lines of weakness in the Sepah-Meusah-Kandoh Group and in the Gajah-Tempurong cliffs.

The Kinta district affords very clear direct evidence of the limestone-hills being due to faulting on a large scale, and of the granitic margin of the Main Range being a line of fracture. In Pahang, where the limestone-hills are fewer, direct evidence is so far wanting as to both points; but it is safe to conclude that the conditions are the same. The Kinta district also affords evidence of magmatic stoping on a grand scale.

The Benom Anticline, too, should be described strictly as an anticlinorium. The Main Range Foothills constitute the western limb of Gondwana rocks. In the centre of Ulu Pahang occurs

[1] See 'The Gopeng Beds of Kinta' Q. J. G. S. vol. lxviii (1912) pp. 125–55.

[2] One outlier of phyllites is known near Gopeng within the granite-area. There may, of course, be other such outliers.

the older Raub Series, with outlying patches of Gondwana rocks and the Benom Granite; while the Main Gondwana Outcrop, less disturbed by folds and faults than the Gondwana rocks of the Main Range Foothills, forms the eastern limb of the anticline.

This, then, is the foundation of the structure of the Peninsula: two great anticlinoria side by side, the formation of which admitted of the intrusion of the granite of the Main Range and of the Benom Range. It will be noted, moreover, on the sketch-map (Pl. XXXV) that the prolongation of the Peninsula as far as Singapore is, in all probability, due to the resistant character of the Gondwana rocks n the eastern limb of the Benom anticlinorium. It is, perhaps, partly due also to minor intrusions of granite that have added to the power of resisting the agencies of weathering.

XII. Special Points in connexion with the Benom Anticline.

There are some special points worthy of note in connexion with the Benom Anticline. The first concerns the Tahan Range, which forms, in the north of Pahang, the western border of the Main Gondwana Outcrop. This range rises to over 7000 feet, and the altitude of the rest of the outcrop is insignificant compared with it. Gunong Tahan is the highest peak in the Peninsula, but its raison d'être is unexplained. The extraordinary course of the Tembeling River shows that the mountain must long ago have constituted a formidable obstacle, turning the river sharply southwards; but it is not clear why it should be so much more resistant to denudation than the rest of the Main Gondwana Outcrop. It may be that intrusions of igneous rocks which do not appear on the surface are the cause: yet this hardly seems probable. A more likely explanation is that when the Peninsula, in late Tertiary times or later still, was an island or group of islands (a subject which will be discussed on a subsequent page) the sea advanced over the greater part of the Main Gondwana Outcrop, reducing it by denudation, but receded before it could attack the portion of the outcrop which is now the Tahan Range.

Another circumstance is that there is a marked difference between the mineral products of the Benom Anticline and those of the Main Range Anticline. The chief products of the latter are tin-ore and wolfram. In the former, however, tin-ore is scarce; but gold in small quantities is widespread, while rutile and zircon are known to occur in some abundance.

Those who have read books on the Malay Peninsula will have noticed references to a 'gold-belt' stretching from Negri Sembilan through Pahang and into Kelantan. Until I had worked in Ulu Pahang for some time, the existence of this belt, in which gold is undoubtedly more abundant than elsewhere in the Peninsula, puzzled me. It is now clear, however, that the area covered by the Benom Anticline is the gold-belt; and, if one remembers that the Benom granite-mass is mostly hornblende-granite, with which syenites are associated, also that in this area the dacites, andesites,

and dolerites of the Pahang Volcanic Series have their greatest development, it is unnecessary to quote scientific literature to show that the difference in mineral products is consequent on the difference between the nature of the igneous rocks in the Benom Anticline and those in the Main Range Anticline. East of the Benom Anticline are stanniferous granites similar to the Main-Range granite.

This difference between the rocks of the Benom Range and the tin-bearing granite-ranges leads on to another interesting subject, which it is impossible to discuss fully here—although it may be mentioned briefly. When describing the rocks of Pulau Ubin and Pulau Nanas,[1] I remarked on the early differentiation of a granitoid and a gabbroid magma under the site of the Peninsula and the neighbouring Archipelago. Now, in the Benom Range pyroxene-biotite-syenite has been found; and to the south, in the Rumpin district, a fine-grained norite has been collected, the relation of which, however, to the Benom Granite is obscure. The presence of norite suggests another intrusion from the same or from another gabbroid magma, and the presence of the pyroxene-bearing rocks in the Benom Range suggests a probability of their connexion with a gabbroid magma also. The difference between the felspars in the Benom pyroxene-bearing rocks and those in the Pulau Nanas pyroxene-bearing rocks is against their direct origin from the same magma; but it will be allowed that such rocks might be derived ultimately from the same gabbroid magma, if we consider the possibilities of a preliminary magmatic differentiation and the chances of admixture of the granitic magma. The less acid character of the Benom rocks, as a whole, compared with the rocks of the Main Range, may be due to such a mixture of magmas. It might, however, be argued that the abundance of hornblende-granite in the Benom Range is due to the melting of masses of calcareous Raub-Series rocks in the magma before it solidified. I do not incline so much to this view, however, because in the Main Range it is clear that enormous masses of calcareous rocks must have been stoped away—yet hornblende-granites are not, by any means, so strongly developed as in the Benom Range. It is quite likely, nevertheless, that the masses of calcareous rock stoped away in both ranges gave rise to some hornblende.

It is interesting to recall Prof. F. Lœwinson-Lessing's views on the origin of igneous rocks in this connexion.[2] He regards a granitic and a gabbroid magma as the two principal magmas from which all igneous rocks have been derived, and favours the view that all syenites are only local facies of a granitic or gabbroid magma. This is certainly the case with a syenite near Taiping, in Perak, the rock being a local modification of granite; but, in the case of the pyroxene-syenites of the Benom Range, a mixture of two magmas seems to be the more probable cause of their formation.

[1] Q. J. G. S. vol. lxvi (1910) pp. 432–33.
[2] 'The Origin of the Igneous Rocks' Geol. Mag. dec. 5, vol. viii (1911) p. 254.

XIII. Tertiary and Recent Changes in the Peninsula.

From the evidence in the Archipelago of the existence of Eocene rocks, some containing granite-pebbles, we must conclude that, after the granite had solidified, rapid denudation of superincumbent deposits (which have now disappeared entirely) brought the granite and the rocks of the two anticlinoria to light. The only record of Tertiary deposits known so far in the Peninsula is afforded by the Coal Measures in Selangor; these may be Miocene, and of them I need say no more now.

Biological evidence, as shown by Dr. A. R. Wallace in 'Island Life' 1880 (p. 362), points to the Peninsula and Archipelago having formed one mass of land during some part of the Tertiary Era, and the shallowness of the sea which surrounds the islands of the Archipelago, and borders the Peninsula and Siam, shows that no very great elevation would be required to restore these conditions as far as the Straits of Macassar, between Borneo and Celebes. In the Peninsula itself, however, there is evidence that a period of elevation is now actually in progress. This evidence is the existence of old sea-beaches inland. One well-preserved beach can be seen at the foot of Gunong Geriang, near Alor Star; another in the flat country between Telok Anson and the sea. But more than this, there is evidence showing that the Peninsula, not so very long ago, was itself an island, or group of islands, formed of what are now the mountain-ranges. The low country to the west of the Kedah-Singgora Range, without any important stream, can only be regarded as a plain of marine denudation. The Kedah River comes down from the hills that once formed part of the island or island-group. Better evidence than this is that adduced by Mr. H. N. Ridley, who shows that the difference between the present floras of Lower Siam and the Peninsula south of Kedah Peak is sufficient to suggest that the latter was separated by sea from the land on the north.[1]

This combined geological and botanical evidence adds an interesting chapter to the history of this part of the world, of which we have not yet seen the end. After the destruction by submergence of the land-connexions that allowed the faunas of Borneo, Java, and Sumatra to migrate from the north, the subsidence continued until the Peninsula became an island. Subsidence then gave place to elevation, the Peninsula came into being again, and there is in progress a gradual approach to the old conditions of an united Peninsula and Archipelago.[2]

[1] H. N. Ridley, 'An Account of a Botanical Expedition to Lower Siam' Journ. Straits Branch Asiat. Soc. No. 59 (Aug. 1911) pp. 29, 30.

[2] In the paper on 'The Geology & Mining Industries of Ulu Pahang' I have endeavoured to put forward an explanation for the course of the Pahang River. As may be seen from the sketch-map accompanying that paper, the Pahang River suddenly turns at right angles, and flows through the Main Gondwana Outcrop. The suggested explanation is that the Pahang River once flowed on southwards, and emptied itself into the Straits of Malacca near the mouth of the present Muar River, in Johore, but was captured by a small river that cut back through the Main Gondwana Outcrop (*op. cit.* pp. 7–9).

XIV. The Formation of Lignite in Limestone-'Cups.'

The association of lignite and sand with the formation of 'cups' by solution in the limestone under the glacial clays in Kinta

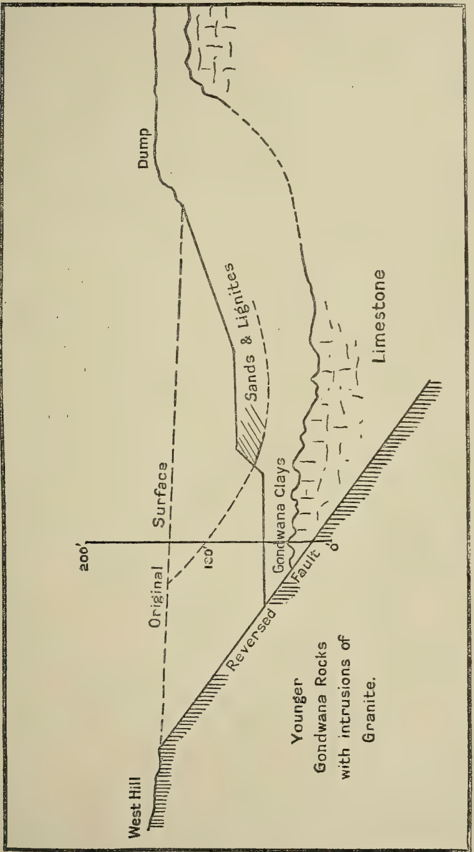


Fig. 2.—*Section of the Tronoh opencast mine, looking north-north-westwards.*

[The above is reduced from a section drawn to scale. The vertical line gives heights in feet. The original surface is indicated by a broken line. The western wall of the opencast mine coincides with the reversed fault-plane: the presence of this fault was probably the cause of the formation of the 'cup' in the limestone, surface-water finding it an easy channel downwards. The curved broken line indicates the probable inclination of the Gondwana clays before mining operations were begun.]

demands attention, not only because it constitutes an interesting type of recent deposit, but also because it proves on examination to be a good example of the growth of coal *in situ*. The formation of

the limestone-'cups' is simple. The limestone is traversed by abundant fault-, joint-, and bedding-planes, which give facilities for attack by water percolating down slowly from above or by springs rising from below. Part of one divisional plane may afford an easier means of attack than another, with the result that there the limestone is dissolved away more quickly. This soon shows itself in the formation of a 'cup' or trough on the surface of the limestone, into which the glacial clays must sink, forming a lining to the cavity. The centre of the cavity becomes filled with whatever lies above the glacial clays. The distances from the top of the pinnacles of the limestone-surface to the bottom of the 'cups' has not been measured systematically, but the average is probably about 35 feet. The deepest and most interesting of all the 'cups' known to-day is that in which the famous tin-deposits of the Tronoh Tin-Mining Company lie. Fig. 2 (p. 363) gives some idea of this 'cup,' and it will be noted that one side of it is bounded by a reversed fault, whereby the limestone and glacial clays have been pushed up against the younger Gondwana rocks.

The infilling of the 'cups' is generally lignite, mixed with a certain amount of sand, which in some cases forms distinct beds. It is only necessary to consider the course of events, if a stream were to flow over the site of one of these 'cups' when it first began to be formed, to understand the significance of the deposit of lignite. The solution of the limestone under the clay would result in a subsidence of the surface over which the stream was flowing. This would lead to the formation of very marshy ground, where the dead vegetation of the tropical forest would fall and accumulate, mixed with alluvial sand brought down into the swamp from higher ground. So long as the limestone continued to dissolve, the subsidence and accumulation of dead vegetation and alluvial sand must have continued also—sinking ever farther down into the 'cup,' and affording an example of the growth of coal-deposits *in situ*.

XV. Torrential Deposits.

When the idea that the clays of the Kinta Valley are glacial deposits first presented itself, particular care was taken to avoid the mistake of ascribing to glacial action boulder-deposits that might have been formed under torrential conditions. The fact that there are in the Peninsula recent torrential deposits, although of a peculiar type, was of great assistance. A brief account of them will be of interest.

A feature of the granitic outcrops is, that to a depth of 20 or even 30 feet, they are weathered to a soft sandy clay that can be cut by hand, but in which veins and faults may still be clearly distinguished. In this granitic clay are numerous cores of hard granite that have resisted weathering. They are of rounded outline, and when divested of their clayey envelope are generally mistaken for waterworn boulders. In order to distinguish them from waterworn boulders, I have always referred to them as 'core-

boulders.' When the decomposed granite is attacked by the mountain-torrents, it is evident that the clay and sand will be washed away, and that the core-boulders will accumulate as huge masses of rock, packed close together and lying on unweathered or partly-weathered granite, in the beds of the streams. The core-boulders themselves act as checks for sand coming down with the stream from above, and the interstices between the lower core-boulders are partly or wholly filled with sand. Sometimes one finds in the jungle a large deposit of core-boulders, and can hear the stream rushing through them far below and out of sight. Chinamen burrow among them to get the tin-ore concentrated behind them by nature, and not uncommonly are killed in the process by upsetting the equilibrium of some tons of hard granite.

A demonstration of how such accumulations of core-boulders can be formed by torrents was afforded in December 1911 in Ulu Pahang, when a terrific downpour of rain struck the slopes of the granite-mountains on which the Trunk Road from Selangor descends to a little township called Tras. The effect of this downpour had to be seen to be believed. Acres of jungle-soil, trees, and core-boulders went crashing down the hillsides under the extra weight of water, the Trunk Road in many places disappearing with them. The small streams became roaring torrents, hurling boulders and trees into the main stream far below, and on to portions of the road that had escaped total destruction. Part of Tras, at the foot of the range, was overwhelmed by the masses of coarse sand poured down the mountain-side.

There is a difference between these torrential accumulations of core-boulders and the glacial clays of Kinta that is readily distinguished. The former have been formed by the s o r t i n g action of water: the case of Tras shows this clearly. The boulders were left heaped up in the hills, boulder touching boulder or resting on hard rock. The sand was swept down to Tras, and dumped there on the flat land. The clay went farther still. Ultimately, we may expect, the interstices between the boulders will be filled up, in part at any rate, with sand brought down by the streams when they are low; but no one who had seen such deposits would be able to conclude that the boulders had been deposited in the sand, or at the same time as the sand. In the glacial clays, on the other hand, there is striking evidence of the absence of the sorting action of water, which alone makes it impossible to regard them as torrential deposits; and with the exception of one case, at Redhills (in Kinta), the boulders are not heaped up together or touching one another.

XVI. Conclusion.

The object of this paper being to give some idea of the geological history of the Peninsula, I cannot discuss at any length the connexion of rocks in the Peninsula with rocks in the Archipelago, Cochin China, the Shan States, and Burma. That there is a close

connexion between the rocks in these regions may be regarded as probable on structural grounds; but, in the case of all the countries mentioned, nothing is needed so much as detailed palæontological research, which cannot be undertaken by geologists who are engaged in economic work. The Dutch geologists are very little or no better off in this respect than myself, if the comparatively greater extent of the area with which they have to deal is considered. The small collections of fossils obtained do but serve to give a rough notion of the geological horizons.

There are two points, however, that I would mention. One is the relation of the Raub Series to beds some distance away to the north. Dr. J. M. Maclaren, in his work on 'Gold; its Geological Occurrence & Geographical Distribution' 1908 (p. 287), seems to be of the opinion that the Raub Series will, on examination, prove to resemble closely certain limestones and shaly beds in the Southern Shan States, described by Mr. C. S. Middlemiss,[1] which have been referred to the horizon of the Middle *Productus* Beds. I have not seen the limestones of the Southern Shan States, and Dr. Maclaren, I believe, has not seen those of the Raub Series; but it may be that the prediction will prove correct, even if the close resemblance is to include contemporaneity. The only way to prove it, without very good palæontological evidence, is to survey the long stretch of country between the Southern Shan States and the Peninsula.

In the Northern Shan States the Napeng Beds are found lying unconformably on limestone, or separated from it by faults.[2] This is suggestive of the relations between the Malayan Gondwana rocks and the Raub Series, and it would not be surprising to find that the Napeng Beds have the same relation to the Gondwana rocks of India as the Malayan rocks. The beds overlying the limestone in the Southern Shan States, again, are described as being 'let down by faulting' or 'tucked in along certain lines and axes of reversed folds and faults,'[3] but there does not seem to be a close resemblance petrologically to the Malayan Gondwana rocks.

The limestones in Indo-China also, referred to the Permo-Carboniferous, may ultimately prove to be part of the same formation as the Raub Series (see p. 353).

At present, the most important point to remember in this connexion is that, taking the glacial horizon in Perak as being equivalent to the Talchir and other contemporaneous late Palæozoic glacial deposits, the attempts to correlate the Raub Series with the *Productus* Beds of the Salt Range on the scanty palæontological evidence[4] must be abandoned, unless we assume the series to be contemporaneous with the shales underneath the boulder-bed in

[1] 'Report on a Geological Reconnaissance in Parts of the Southern Shan States & Karenni' Gen. Rep. for 1899–1900, pp. 130 *et seqq.* (Geol. Surv. India, 1900).

[2] M. Healey, 'Fauna of the Napeng Beds, &c.' Pal. Indica, n. s. vol. ii (1908) Mem. 4, p. 1 (Mem. Geol. Surv. India).

[3] C. S. Middlemiss, *op. supra cit.* p. 143.

[4] See, for example, Geol. Mag. dec. 5, vol. iv (1907) pp. 565, 566.

the trans-Indus section of the Range.[1] If ultimately it should be proved that the limestones of the Southern Shan States are the same as those of the Raub Series, then it would follow that those also are older than the *Productus* Beds of the Salt Range, with the same reservation regarding the trans-Indus section.

The other point is the continuation of the rocks of the Peninsula beyond Singapore. I have already quoted Prof. Suess [2] as follows:—

> 'Still further south this long granite range [the Main Range] breaks up into isolated ridges, and, associated with ancient sediments, reaches the sea near Singapore. A series of cliffs and smaller islands reveals its continuity with the tin-producing islands of Banka and Billiton.'

Unless we interpret 'near Singapore' as meaning Negri Sembilan and Malacca, which to my mind is impossible, we cannot accept this statement as giving the facts of the case. The Main Range tails off in Negri Sembilan; Mount Ophir may be the end of the Benom granite-intrusion; and there is very good reason for supposing that the Main Gondwana Outcrop is continued into the island of Singapore. A glance at an atlas will show that we may expect the rocks of this Gondwana outcrop to be represented in Banka and Billiton. More I cannot say, as I have not visited these islands, but Dr. Verbeek's description does not show anything that makes the continuation improbable, except perhaps one item regarding the relations of radiolarian chert and sandstones.[3] The fact of the granite in these islands being stanniferous is no difficulty. This characteristic does not imply that the granite must be a continuation of the Main Range of the Peninsula; but only that it is probably of the same age as that granite and the granite of other ranges in the Peninsula, including ranges east of the Main Gondwana Outcrop.

Prof. Suess shows in a map [4] trend-lines continuing from Billiton to Karimoen Djawa, off Java. Dr. Verbeek, in his map of Banka and Billiton,[5] shows the lines of strike running through Banka in a south-easterly direction, then across nearly due east to Billiton. In Billiton they run almost due east at first, then fall away to the east-south-east, with which strike they leave the island. In Nangka and another island the strata show a strike almost due south-east, but these trend-lines are shown as turning up again to the east. This is interesting, as indicating that, while the rocks of Karimoen Djawa may mark a reappearance of the Banka and Billiton rocks, some of the Billiton rocks, which may be a continuation of the Main Gondwana Outcrop of the Peninsula, bend round as though to enter Western Borneo: the curve being an inside arc roughly parallel to the outer volcanic arc that runs down the

[1] 'Manual of the Geology of India,' p. 120.
[2] 'The Face of the Earth' Engl. transl. vol. iii (1908) p. 233.
[3] R. D. M. Verbeek, 'Geologische Beschrijving van Bangka & Billiton' Jaarb. Mijnw. Nederl. O.-I. vol. xxvi (1897) Wetensch. Gedeelte, pp. 92–93.
[4] 'The Face of the Earth' Engl. transl. vol. iii (1908) pl. ii, p. 235.
[5] 'Geol. Beschr. v. Bangka & Billiton' Map No. 1.

western coast of Sumatra, through Java, and so up to the Philippines. Perhaps some of the rocks of Western Borneo described by Wing Easton,[1] some of those of Central Borneo described by Dr. Molengraaff,[2] and the Middle Oolite of Sarawak described by Mr. R. B. Newton and myself[3] will ultimately be connected with the Malayan Gondwana rocks. They show characteristics of deposition in a deeper sea; but that is only to be expected, seeing that once we turn eastwards we are receding from the site of the coast of Gondwanaland.

The geological history of the Malay Peninsula, as traced in this paper, may be summarized as follows:—

During the Mesozoic Era earth-movements took place in a part of the crust which is to-day the site of the Peninsula. These movements resulted in the formation of two large anticlinal folds. The folding admitted of the intrusion of two masses of granite, and the intrusion was accompanied by faulting of the rocks in the folds and by 'magmatic stoping' on a large scale.

The rocks affected by the folding are the calcareous Raub Series and the Malayan Gondwana rocks, resting unconformably on the Raub Series and in many places faulted down against it.

The palæontological evidence afforded by small collections from the Raub Series cannot be reconciled with the field-evidence. No fixed horizon has been discovered in these rocks, which may be Carboniferous or Permo-Carboniferous. Associated with the Raub Series are volcanic rocks that are evidence of contemporaneous submarine eruptions. The eruptions continued into later times.

At the base of the Gondwana rocks are glacial deposits, which may be referred to the same horizon as the late Palæozoic glacial deposits of Peninsular India, the Salt Range, Australia, and South Africa; but this horizon cannot be defined exactly in the terms of the European sequence. Its presence shows that the Raub Series must be older than the *Productus* Beds of the Salt Range, or equivalent to the shales below the boulder-bed in the trans-Indus section of the Salt Range.

The glacial deposits are succeeded by littoral deposits, and a long way east of the former a Rhætic horizon has been described in the latter by Mr. R. B. Newton, and named by him Myophorian Sandstone. To account for the apparent discrepancy in age between the climatic horizon afforded by the glacial deposits and the Myophorian Sandstone, an hypothesis has been adopted to the effect that the Malayan Gondwana rocks were deposited on the Gondwanaland coast-line as it moved slowly eastwards, probably with many checks and oscillations.

[1] 'Geologie eines Teiles von West-Borneo' Jaarb. Mijnw. Nederl. O.-I. vol. xxxiii (1904) Wetensch. Gedeelte.

[2] 'Geological Explorations in Central Borneo' London 1902.

[3] Geol. Mag. dec. 4, vol. iv (1897) pp. 407–15; also 'Report on the Geology of Sarawak' published in the F.M.S. Government Gazette, 1904.

The glacial deposits show that this portion of the Gondwanaland coast contained stanniferous granite and also much corundum. This granite is termed the Palæozoic Granite, as distinguished from the Mesozoic Granite. It is not known *in situ*. The glacial deposits are, therefore, part of a Palæozoic tin-field, now being worked at the same time as the tin-deposits derived from the Mesozoic Granite.

Denudation has brought to light the two great anticlinal folds and the granite-masses upon which they now rest. On the west is the Main Range Anticline, on the east the Benom Anticline. The eastern limb of the former and the western limb of the latter meet in the Main Range Foothills. The eastern limb of the Benom Anticline is formed by the Main Gondwana Outcrop, which includes the highest peak in the Peninsula—Gunong Tahan, 7188 feet above sea-level. It is believed that this Main Gondwana Outcrop is continued through the Peninsula to Singapore, and thence on to Banka and Billiton, where it may turn so as to enter Western Borneo, forming an inner arc roughly parallel to the outer volcanic arc of the Malay Archipelago and the Philippines.

The igneous rocks of the Benom Anticline are less acid than those of the Main Range Anticline, and there is a corresponding difference in mineral products. The area of the Benom Anticline coincides with the 'gold-belt' of the Peninsula. The chief products of the Main Range Anticline are tin and wolfram.

Tertiary Coal Measures, unconformable on the Gondwana rocks, are known in Selangor. Their exact age cannot be determined, since the flora resembles the existing jungle-flora, and the same may be said of floras in Borneo Coal Measures that are believed to date back to the Eocene. A classification based on the percentage of moisture in the coal, however, points to the possibility of their being Miocene.

Evidence has been found in the Peninsula supplementing the biological evidence adduced by Dr. A. R. Wallace of changes in the Archipelago in Tertiary times. When the land-connexion that allowed the migration of the fauna of the Archipelago from the north was destroyed by submergence, the subsidence continued until the Peninsula became an island or group of islands. Subsidence then gave place to elevation, which restored the Peninsula and is continuing to-day.

Interesting recent deposits are deposits of lignite, in 'cups' formed by solution in the limestone of the Raub Series, as also torrential deposits formed of 'core-boulders' derived from weathered granite.

EXPLANATION OF PLATE XXXV.

Sketch-map of the Malay Peninsula, showing diagrammatically the chief structural features, on the scale of 48 miles to the inch or 1 : 3,041,280.

Discussion.

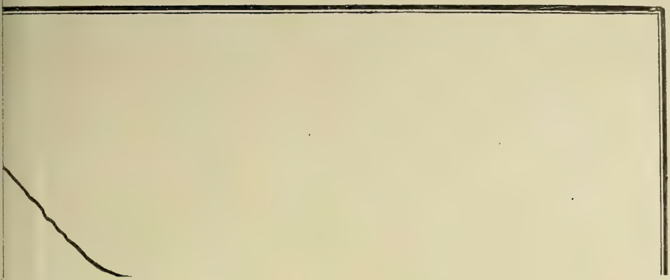
Mr. R. D. Oldham congratulated the Author on the interesting and connected account that he had produced of a country regarding which only scattered information had been accessible, and in which geological work was very difficult. Personally, he had been more especially interested in the portion dealing with what the Author had called the 'Malayan Gondwana rocks'; these evidently comprised rocks of the same age as those that are included in the Gondwana System of India, but differed in type from the rocks to which that name was generally restricted. The discovery of beds of glacial origin which could be reasonably ascribed to the same age as the Talchir boulder-beds of India was especially interesting. The magnificent series of photographs exhibited showed most clearly that these beds present most, if not all, of the characters on which the belief in the existence of glaciers descending to low levels is based in India, South Africa, and Australia; but the acceptance of a glacial origin for these rocks, taken in conjunction with the reported occurrence of glacial beds of similar age in South America, and with the complete absence of any comparable deposits in Europe, Northern Asia, or North America, led to the extraordinary conclusion that in Permian times the equatorial regions were characterized by a colder climate than the polar regions.

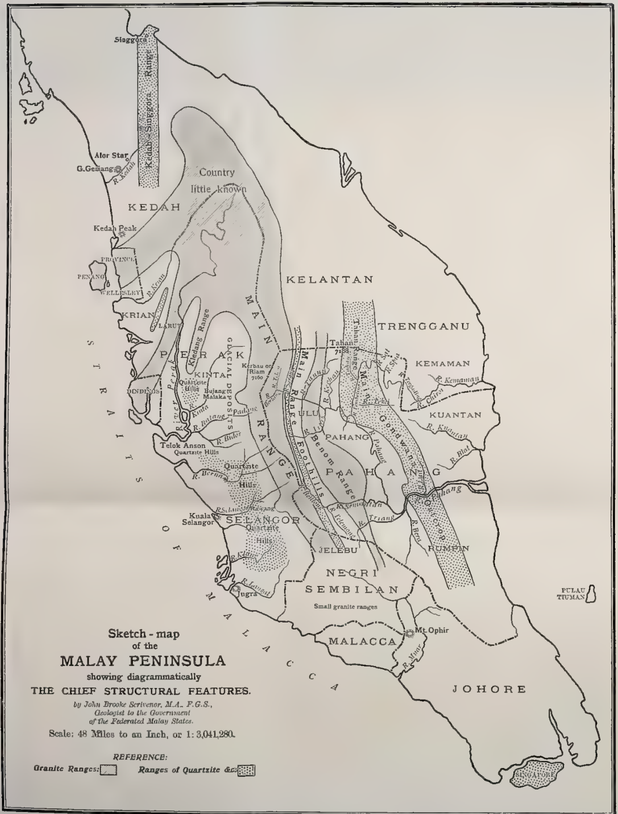
Mr. R. Bullen Newton stated that he had been privileged to aid the Author in the palæontological section of his work, as many interesting fossils had been sent to the British Museum for determination. The oldest forms examined were some cephalopod-remains yielded by the limestones of Mill Gully and Gua Sah, which Mr. Crick had recognized as *Solenocheilus*, *Cyrtoceras*, *Orthoceras*, etc. The first-named genus is of chief importance, since it belongs exclusively to the Carboniferous Limestone Series, and might be regarded as indicating an horizon about that of the Viséan deposits of Belgium; the limestone could not, therefore, be considered as of later age, as had been suggested in the paper.

Permian rocks were represented at Lubok Sukom, and had yielded impressions of the ammonoid genus *Xenodiscus* and *Dentalium* cf. *herculea*; both forms have been described by Waagen as occurring in similar association in the Upper *Productus* Limestone of India, an horizon approximately equivalent to that of the latest Permian deposits of Europe.

The marine shells from Singapore found in association with land-plants (*Podozamites*), which the speaker had described as of probably about Middle Jurassic age, were of peculiar interest: for the assemblage suggested a possible relationship to Upper Gondwana conditions, more especially as terrestrial and marine organisms in association had been recorded from deposits of Upper Gondwana age in India.

Mr. T. H. D. La Touche remarked that the Raub Series of the Author was apparently a southward extension of a portion of the





Sketch - map
of the
MALAY PENINSULA
showing diagrammatically
THE CHIEF STRUCTURAL FEATURES.

by John Brooke Scrivenor, M.A., F.G.S., Geologist to the Government of the Federated Malay States.

Scale: 48 Miles to an Inch, or 1: 3,041,280.

REFERENCE:

Granite Ranges: *Ranges of Quartzite &c:*

dolomitic limestones that occupy so wide an area in the Shan States of Burma. In the Shan States the sequence of fossiliferous rocks is much more complete than in the Malay Peninsula, extending from Lower Ordovician to Jurassic. To the Silurian succeeds a great thickness of limestones, the lower portion of which is of undoubtedly Devonian age, while the upper contains a well-developed Middle *Productus* fauna. These limestones are known to extend as far southwards as Tenasserim, where Carboniferous fossils were found in them by the late Dr. T. Oldham and Mr. P. N. Bose. The Raub Series, therefore, probably represents the upper part of the Shan States limestones, and points to a transgression of the Carboniferous sea southwards, followed by an eastward retreat of the coast of Gondwanaland. Only one other formation is common to the two areas, the Rhætic or Napeng Beds. In the north there is no trace of the glacial beds described by the Author.

With regard to the correlation of these rocks, attention may be called to the fact that the beds containing a *Glossopteris* fauna, discovered by Dr. Nœtling in Kashmir, have been shown by Mr. Middlemiss to occur beneath a Permo-Carboniferous Series. If, therefore, the Raub Series, even in part, corresponds to any portion of the Permo-Carboniferous Series, it is difficult to understand how the glacial deposits lying above the *Glossopteris* Beds could be the equivalents of the Talchirs of India, which are still older than the *Glossopteris* Beds. The occurrence of *Podozamites*, an Upper Gondwana form, also points in the same direction. Accepting the glacial origin of the deposits, therefore, it would appear that they belong to a later period of glaciation than that represented by the Talchir Beds, and do not affect any of the theories that have been put forward to account for that period.

The Author, in reply, thanked the Fellows for the reception accorded to his paper. Mr. Oldham's recognition of the similarity presented by the Malayan glacial deposits with those in India, Africa, and Australia was very welcome, as the Author for some time had nurtured misgivings on this point. He thought it possible, of course, that all these phenomena which had been ascribed to glacial action might really be due to some unknown agency: but he accepted provisionally the simplest solution, until that agency was discovered.

He agreed with Mr. R. B. Newton that there was great need of more palæontological work in the peninsula; such work might in time clear up the difficulties which Mr. La Touche had raised, and possibly prove the connexion which that speaker had suggested.

18. *On the* Skeleton *of* *Ornithodesmus latidens; an* Ornithosaur *from the* Wealden Shales *of* Atherfield (Isle *of* Wight). By Reginald Walter Hooley, F.G.S. (Read February 5th, 1913.)

[Plates XXXVI–XL.]

Contents.

I. Introduction.

The late Rev. W. D. Fox, of Brighstone (Isle of Wight), discovered in the Wealden Beds of Brook in that island many associated ornithosaurian bones. These were acquired by the Trustees of the British Museum in 1882, when they purchased his important collection. They are numbered R/176, and classified by Mr. R. Lydekker[1] under *Ornithocheirus nobilis* (Owen) as 'not improbably belonging to this species.'[2] In 1888 the hinder portion of the skull was shown by Mr. Lydekker to Mr. E. T. Newton, at the time when the latter was preparing his paper on *Scaphognathus purdoni*; and Dr. Henry Woodward permitted it to be bisected longitudinally, so that Mr. Newton was enabled to describe the form of the brain.[3] No other reference appears to have been made to the fossil until 1901, when the late Prof. H. G. Seeley referred to it in his 'Dragons of the Air' (pp. 173–74), under the name of *Ornithodesmus latidens*, and thus it became the type of that genus. Judging from particulars there given, one would surmise that a much greater portion of the skeleton once existed. At the present time the hinder part of the cranium is the only moiety of the skull to be found; but Dr. A. Smith Woodward informs me that he has heard a tradition that Fox had originally the jaws of this specimen, and that they were lost before the collection came into the possession of the British Museum.

I purpose giving details of the bones comprised in B.M. R/176

[1] 'Catal. Foss. Rept. & Amph. Brit. Mus.' pt. 1 (1888) p. 24.

[2] According to Owen's determination, the type-specimen of *Ornithocheirus nobilis* (*Pterodactylus* Owen) is a part of the second phalange of the wing-finger, but one of the specimens to be reviewed proves it to belong to the central region of the shaft of the ulna.

[3] Phil. Trans. Roy. Soc. 1887 (1888) ser. B, vol. clxxix, pp. 510–11.

for, with those belonging to two other individuals, obtained from the Wealden Shales of Atherfield (Isle of Wight), we have sufficient material to restore the almost complete skeleton of this reptile. The blocks of rock containing the latter have all been recovered from the sea, washed out of an enormous fall of Wealden Shales which occurred near Atherfield Point (Isle of Wight), in the autumn of 1904, the same as that which yielded the skeleton of *Goniopholis crassidens.*[1]

Particulars of the Bones included in the British Museum Specimen, No. R/176.

Skull: The back of the skull from the centre of the orbits. Right side badly worn, the left and occiput well preserved.

Vertebræ: A cervical, much crushed, the posterior end nearly perfect. Fragments of other vertebræ are to be seen embedded in the matrix adhering to the odd bones. The notarium with the ultimate process of the right side preserved, and the left side enveloped in matrix. Five consecutive dorsal vertebræ follow the notarium on the same mass of shale. Only their ventral surfaces are exposed. Three and the proximal end of the fourth sacral vertebræ.

Sternum: Nearly perfect.

Humerus: The right, minus a fragment of the ulnar process near the condyle. A large portion of the left, with the radial process (deltoid crest) well preserved.

Radius and ulna: Proximal ends, sections of the shafts, and the distal extremities of both bones.

Carpals: Several.

Metacarpals: Proximal and distal ends of wing-metacarpal.

Phalanges: Fragments of the wing-phalanges, proximal ends of both right and left first wing-phalanges.

There are also shattered and flattened pieces of limb-bones. Where free from a distorted condition, the above are similar in form and measurement to the corresponding bones in the Atherfield fossils.

Particulars of the Atherfield Specimen, No. 1.

This specimen was contained in three blocks and a rounded pebble, which had become thus by attrition on the beach since its fall from the cliff. The three blocks combined had a length of 540 mm. Two of those blocks fitted together precisely, but the third required a section (which has not been found) to connect it with the other two. As will be proved hereafter, the missing block was originally 89 mm. long. The matrix was a very fine silt, containing both carbonate and phosphate of calcium and iron. Its hardness was extremely variable, and as the bones are of papery thinness and very brittle, their removal without damage was a matter of much difficulty. These blocks held the following bones:—

Skull: The greater portion anterior to the orbits.

Vertebræ: An imperfect cervical, the last two cervicals, the almost perfect notarium, and the first four dorsal vertebræ.

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[1] R. W. Hooley, Q. J. G. S. vol. lxiii (1907) pp. 50–63 & pls. ii–iv.

Scapula: The left, minus a moiety of the humeral end.

Humerus: The proximal and distal ends of the right, and the distal of the left. As the proximal extremity of the former was lying with its ventral surface exposed, the ulnar and radial processes have been worn to their bases. The concavity between them is filled in by matrix, and overlain by the thin plate of the ventral posterior half of the right ischium. The latter bone was once overlying this end of the humerus, but pressure has squeezed that portion above the remainder of the ischium, so that the humerus appears to be resting on that bone. The removal of this fragment has been found impossible.

Radius and ulna: The whole of the right radius and ulna, excepting 89 mm. (the missing section) from their shafts, and slightly more than the proximal halves of the left.

Pteroid: The perfect right pteroid.

Carpals: All of both wrists, except the left lateral carpal.

Metacarpals: The proximal end of the right-wing metacarpal, and one of the small right metacarpals.

Phalanges: The distal extremity of the first, the major portion of the second, and the proximal end of the third phalange of the right wing.

Ischium: The almost perfect right ischium.

Particulars of the Atherfield Specimen, No. 2.

The bones of this specimen are in one block, also obtained from the sea, which has likewise worn away the ends of many of them. That it does not belong to the blocks in specimen No. 1 is proved by its containing similar bones. They lie on a layer of hard blue limestone, but are embedded in the same matrix of silt.

The following bones are preserved:—

Scapula: The humeral end of the right scapula.

Coracoid: The perfect right coracoid.

Humerus: The distal halves of both humeri. The dorsal surface of the left and the ventral of the right are exposed.

Radius and ulna: The proximal ends of the left radius and ulna.

Metacarpals: The distal extremity of the right and the distal third of the left wing-metacarpals.

Phalanges: The proximal half of the right and left first wing-phalanges.

II. Description of the Skeleton

The skull is nearest in outline to *Pterodactylus*; but the occiput is square, and not rounded as in the figures and restorations of that genus. The extremity of the snout and the brain-case are the only portions of the skull that are completely enveloped in bone. These two regions are connected dorsally by a triangular bar, and ventrally by thin band-like maxillæ. The tip of the muzzle is truncated. Here both upper and lower jaws are moderately convex from side to side, and gently curved longitudinally. There is neither nerve-pore nor foramen visible on the upper and lower jaws.

The upper jaw, 33 mm. from the tip of the muzzle, or above the seventh tooth, becomes laterally compressed—a compression which gradually intensifies, until at the commencement of the nares, the sides are decidedly concave. The dorsal outline of the beak makes a very acute angle with the lower jaw, which is

straight. There is no supra-occipital crest. The parietal region is but slightly convex from side to side, and, compared with the length of the skull, extremely constricted.

There is no longitudinal arching of the cranial platform or the occiput (Pl. XXXVII, fig. 3). The crown and lateral borders of the back of the skull are semicircular, and the base concave (Pl. XXXVIII, fig. 1). The lower outer border is produced posterior to the condyle. The intermediate area is deeply concave. The brain-capsule is very small.

I estimate the length of the skull to have been 560 mm., and that of the mandibles 423 mm., which I obtain in the following manner. From the angles at which the proximal and distal ends of the humerus, radius, and ulna were lying on the blocks, the missing section must have been about 89 mm. long. In the measurements of the skull and limb-bones I have taken this to be the length of the lost section. This would give the humerus the same length as the British Museum specimen, which is 220 mm. long; and, as the preserved portions of that bone in the Atherfield fossil are of the same size, it is no more than what would be expected.

The Vacuities of the Skull.

The External Nares.

The external nares (Pl. XXXVII, fig. 1, *n.v.*) begin not far from the extremity of the snout. They gradually expand backwards 140 mm. Here should occur the missing section, and all further trace of their shape and area would be lost, were it not for a moiety of bone (Pl. XXXVII, fig. 4, *mx.n.b.*) 50 mm. long and 18 mm. deep, attached to the inner face of the maxilla, 236 mm. from the end of the muzzle. This bone shows a thickening at its upper interior edge. The lowest portion of the anterior border exhibits a curved smooth outline, the extreme lower anterior boundary of the antorbital vacuity, for I take this fragment of bone to be the lower end of a maxillo-nasal process. It has on its upper extremity a jagged fracture, thus proving a continuation of the bone in that direction. Perhaps additional proof is added by the beak breaking across, just posteriorly to this process, the weakest place in its length. Again, if the narial opening was confluent with the antorbital vacuity, the great cavity from the anterior border of the nares to the anterior margin of the orbit, taken in conjunction with the weak premaxillar bar and attenuated maxillæ, would appear to have been unable, without a strut, to prevent crumpling on a strain of the jaws in prehension, for the weight of the skull is distributed at both extremities. I believe that the rest of the maxillo-nasal bar has been destroyed, and that the nasal was not confluent with the antorbital vacuity. Granting this, the nasal opening is enormous, subtriangular in shape, slightly oblique in position, and posterior to the teeth.

The Antorbital Vacuity.

The antorbital vacuity (Pl. XXXVII, fig. 2, *a.o.v.*) is large, elongately rhomboid, entirely separated from the orbit and the nasal opening.

Antorbital Vacuity No. 2.

An additional preorbital vacuity (Pl. XXXVII, fig. 2, *a.o.v. 2*) is situated in front, beneath, and confluent with the orbit. It is shuttle-shaped, obliquely placed, and bounded by the jugal above and the quadratojugal beneath. In a profile view of the skull its width appears much less than it is in reality.

The Orbit.

The orbit (Pl. XXXVII, fig. 2, *O.*) is small, circular, and placed very far behind the mandibular articulation. Except the narrow opening into the antorbital vacuity No. 2, it is entirely surrounded by bone. The anterior margin is formed by the extreme proximal end of the jugal and a moiety of the lachrymal, the roof by the prefrontal and the frontal, and the posterior border by the postfrontal and postorbital: that is, if we take this buttress to 'include both these elements, as in *Sphenodon*.'[1] Its lower boundary is formed entirely by the quadratojugal, which here is hollowed as far as the anterior region of the orbit, where a broadening of the bone determines the extent of, but does not complete, the orbital rim. There was no trace of a sclerotic ring.

The Supra-Temporal Fossa.

The supra-temporal fossa (Pl. XXXVII, fig. 3, *s.t.f.*) is deep, large, and thrown open laterally, because of the supra-temporal arcade rising obliquely forward from the lowest point of the outer edge of the back of the skull. It is bounded on its posterior and lower borders by the squamosal and a process from that bone, and anteriorly by the post-fronto-orbital buttress.

The Infra-Temporal Fossa.

The infra-temporal fossa (Pl. XXXVII, figs. 2 & 3, *i.t.f.*) is large, directed obliquely, and extends in front of and behind the orbit for equal distances. It is bordered above by the squamosal bar and the quadratojugal, and below entirely by the quadrate. The inner hinder border of these bones forms a rising floor under the posterior end of the vacuity, which prevents its full extent from being observed in a profile view.

[1] E. T. Newton, Phil. Trans. Roy. Soc. 1887, ser. B, vol. clxxix (1888), p. 506.

The Bones of the Skull.

The Premaxillæ.

The premaxillæ (Pl. XXXVII, fig. 5, *p.*) comprise the whole of the upper jaw anterior to the nares, and include the whole alveolar tract of each side. Dorsally they are produced backwards as a triangular rod, which is nowhere wider than 15 mm. This bar is prolonged to the frontal, but to what distance they continue to take a share in it is not clear. The premaxillo-maxillar suture is apparently beneath the anterior edge of the nares.

The Maxilla.

The maxilla (Pl. XXXVII, figs. 2, 4, & 5, *m.x.*) is an extremely thin, long, narrow bar of bone, of little depth. There is a slight increase in depth at each end, with the posterior extremity the more expanded. Here the inner dorsal margin is raised above the outer, and on its posterior border it is fused to the jugal. Its exterior surface is concave. Near the tip of the snout, and below the anterior end of the external nares, the inner ventral margin is produced inwards, as a sheet of bone, and meets a similar process of the maxilla of the opposite side, completely roofing the palate. How far backwards this plate was continued, it is impossible to say, on account of the lost section. The maxilla comprises the inferior boundary of the nasal and antorbital vacuity, and extends to the quadrate, without the intervention of the jugal. The maxilla is edentulous.

The Nasal.

The nasal apparently sends down a process to join that of the maxilla, nearly midway between the anterior end of the nasal and the posterior extremity of the antorbital fossa. That this is so seems to be proved by the presence of the maxillar process: for, where the nasal and preorbital opening is confluent, as in *Pterodactylus*, such a process is not found. The nasals are fused with the backward extension of the premaxillæ into a single median ossification. What extent of this dorsal bar they occupy is indeterminable.

The Lachrymal.

The lachrymal (Pl. XXXVII, fig. 5, *l.*) is situated in the upper anterior corner of the orbit. It looks forward into the antorbital vacuity. It is triangular, with the apex of the triangle pointed downwards, and bifurcated: the two branches unite with the upper end of the jugal, and form together an elongated foramen. Where it shares in the orbital rim, it is strongly convex, and, between here and the prefrontal, concave.

The Frontal.

In the Atherfield specimen No. 1, only the extreme anterior end of the frontal is seen. It commences over the anterior third of the orbits, and here on the right side is a curious mammillated knob of bone (Pl. XXXVII, figs. 2 & 5, *b*.) over the upper border of the orbital rim, which most probably was paired on the left. Interiorly to this boss, the surface is concave, rising into a feeble convexity on the summit of the cranium. The frontal unites with the lachrymals, prefrontals, and the premaxillar prolongation with a V-shaped suture, the angle being towards the occiput. It lies below the prefrontals and the premaxillar extension, but not beneath the lachrymals along the line of suture. In the hinder portion of the skull in the B.M. R/176 specimen, the extent of the frontal and the other bones of the cranial roof cannot be seen. The cranial platform is a quadrilateral space.

The Post-Frontal.

The post-frontal is situated in the corner between the orbit and the supra-temporal fossa. It sends down a process which, in conjunction with the post-orbital (if that bone be present), comprises the posterior boundary of the orbit.

The Parietal.

The parietal arches the skull between the supra-temporal fossæ. It is extremely constricted, so that it becomes very concave on its lateral borders. At its junction with the occipital area the bone is raised.

The Squamosal.

The squamosal is situated at the posterior lower angle of the supra-temporal fossa. It sends forward and upwards a process to unite with the post-fronto-orbital bar, in forming the supra-temporal arcade. Below, it is fused to, and rests upon, the hinder end of the quadrate: this forms a strong buttress, upon which the brain-case is supported.

The Bones of the Occiput.

The right side of the back of the skull in B.M. R/176 is destroyed, and the left below the foramen magnum is covered by matrix. Nor are any sutures or striæ visible on the upper half, so that the extent of the bones is indecipherable. Except a vertical ridge from the parietal border to the foramen magnum, the whole region between the outer borders is concave. The parietal, squamosals, and paroccipitals have expanded and coalesced into one concave plate, with the post-temporal fossæ almost obliterated. The occipital condyle is large, and, as usual, set at right angles to the skull.

The Vacuities of the Occiput.

The post-temporal fossa of the left side is well exhibited. It is quite small, subcircular, and placed far above the foramen magnum near the upper border of the occiput. The foramen magnum is very large.

The Quadrate.

The quadrate (Pl. XXXVII, figs. 2, 3, & 5, *Q.*) is extremely long. It articulates with the mandibles as much as 99 mm. in front of the orbit. Its proximal end is remarkably robust, and so the overlying cranium is weak and fragile in comparison. It forms a third of the depth of this part of the skull. Its proximal dorsal half bends inwards under the supra-temporal arcade. Proximally, externally, it is fused with the squamosal process, between which and the paroccipital process it is immovably wedged. It lies under the squamosal, and forms the lowest angle of the posterior end of the skull. In the median region it is much weaker, and moderately thick; its dorsal half loses the inward curve, and the whole lateral surface looks outwards. This continues to the distal end, where the bone again becomes more powerful, with a stout, convex, ventral border. Dorsally here it is anchylosed to the quadratojugal for 51 mm.; proximally to this it comprises the lower boundary of the infra-temporal fossa. From the interior surface at its distal end a strong bar of bone extends 29 mm. upwards and backwards. The angle thus made with the shaft of the quadrate is occupied by a wing of thin bone, which has its origin 86 mm. from the articular end. The pterygoid probably united with the inner angle of this wing, as in *Scaphognathus purdoni.* The type of *Sc. crassirostris* is the only specimen that clearly denotes the form of the inner side of the quadrate. It exhibits a corresponding wing, although the distal border is not a straight line, but sigmoid, and the wing is apparently developed to the full extent of the bone. The articulation is a plain pulley-joint, above which the quadrate unites with the lower angle of the posterior extremity of the maxilla.

The Quadratojugal.

The quadratojugal (Pl. XXXVII, figs. 2, 3, & 5, *Qu.*) is a thin moderately-broad bone, rising obliquely from the maxilla to the anterior termination of the squamosal bar, near the hinder border of the orbit. It is anchylosed to the inner side of this bar. For about a fourth of its length it forms the lower boundary of the orbit, and for the remaining three-fourths that of the infra-orbital vacuity. At its lower end it is fused for 51 mm. with the quadrate and at its extremity with the maxilla.

The Jugal.

The jugal (Pl. XXXVII, figs. 2 & 5, *J.*) is a rod-like hollow bone, except at its lower end, where the inner and outer lateral surfaces are flat. It rises obliquely, yet feebly arched, to the lachrymal. Here it is bifurcated into short branches, the outer being club-shaped and passing backwards and downwards, forming a moiety of the anterior margin of the orbit. The inner is rod-like, and connects with the interior border of the lachrymal. The distal termination is **V**-shaped, one branch joining a raised portion of the inner border of the maxilla and the other being fused with the interior surface of the quadratojugal at its dorsal edge. Its total connexion with the maxilla and the quadratojugal is only 5 mm. long.

The Temporal Arcades.

The jugal, quadratojugal, and quadrate all rise obliquely from the maxilla at nearly the same angle and free one from the other. The jugal takes no share whatever in the upper temporal arcade: this is formed by the quadratojugal and the squamosal bar. The squamosal bar overhangs externally the hinder end of both the quadratojugal and the quadrate. The lower temporal arcade is made entirely by the quadrate.

The Palate.

I have not thought it advisable, owing to its hardness, to clear away the matrix which lies in the angle made by the convergence of the mandibles, for fear of fracturing this end of the beak. On the area of the palate exposed, there is no trace of the internal nasal openings, and it is too near the anterior margin of the external nares for them to be situated in front.

The Mandible.

The mandible (Pl. XXXVII, figs. 1, 2, 4, & 5, *mn.*) is long, and the symphysis short. The alveolar tracts terminate close behind the symphysis. The rami of the mandibles gradually decrease in depth backwards; but their strength is maintained by a corresponding increase of the width, and at the articulations they are bulbous. Near the symphysis they are convex ventrally; posteriorly they lose this, and become for some distance flat, with a convex upper and lower border. Behind the premaxillæ, they lie exterior to the upper jaw. On their inner dorsal margin there is a depressed ledge, on which the maxillæ rest, when the jaws are shut. Beneath this shelf, the bone is concave. They terminate far in advance of the orbits. The extent of their different elements cannot be determined.

The Teeth.

There are twenty-four teeth in the upper, and twenty-five in the lower jaw. Only twenty-three of the former are exposed, owing to a slight displacement of the upper jaw; through this derangement the teeth of the right dentary are covered by the matrix underlying the teeth of the right premaxilla, in such a manner that it is impossible to remove it, without endangering the overlying teeth. The hindmost tooth on each side of the lower jaw is posterior to all the teeth of the upper. All the teeth interlock. They are compressed laterally and lanceolate, the smallest teeth being at the tip of the muzzle; these are followed gradually by longer and broader teeth. The two posterior teeth on each side of both jaws are broader, larger, and more bluntly pointed than the rest. A very marked characteristic is that the last two teeth of the mandibles fit into semicircular slots in the upper jaw (Pl. XXXVII, figs. 1 & 5); and the ultimate one of the upper jaw lies exterior to the lower jaw, the lateral outer surface of which is slightly concave to receive it but not slotted. These teeth, in life, must have been visible when the muzzle was closed. They are a little longer than the others. The indentations in the upper jaw give an appearance to the last tooth of being set on the summit of a strong process. The teeth are smooth and free from striæ; but, on careful examination, there is to be discovered, on the outer surfaces of some of them, an incipient median carina. The alveolar borders of the upper jaw, anterior to the slots, are gently convex to the tip of the snout. Those of the lower jaw, immediately in front of the last two teeth, fall abruptly some distance below the plane of the tract occupied by those teeth, and from there they are feebly concave. The posterior tooth of the left dentary is displaced, but attached by matrix to the surface of the bone near the dorsal border of the beak. This tooth is diamond-shaped, both crown and base forming equilateral triangles. All the teeth are vertical, and planted in separate sockets.

The Vertebral Column.

The hinder half of a cervical vertebra in the Atherfield fossil is quite similar to an example in the B.M. specimen R/176. That example is much crushed, and has been fractured and cemented together, so twisted that the dorsal surface of the one portion is followed by the ventral of the other. This is apparently the example figured by Seeley [1]: it is procœlous. The neural arch and spine are missing. In the Atherfield example the neural spine is fairly high and robust, and the neural arches are flat and set at an oblique angle to the spines: they overhang the centrum. The neural canal is large. The centrum is long and narrow, becoming moderately constricted in the central region. Laterally, a deep and

[1] 'Dragons of the Air' 1901, fig. 66 & p. 173.

open valley traverses its length. Pneumatic foramina occur on each side. The ventral surface of the centrum is flat without any carination, slightly concave at both ends, and at the posterior extremity bifurcated into the usual tuberous processes with the articular convexity between, but dorsal to them. The pre-post-zygapophyses arise laterally near the posterior third of the centrum, and are directed backwards, terminating some distance from the posterior articulation of the centrum. A restored ventral view of this cervical is given in Pl. XXXVIII, fig. 2.

The last two cervical vertebræ have their zygapophyses laterally, and centra ventrally, much waterworn. The centrum of the penultimate is twice as long as that of the ultimate, and the neural spine has a greater longitudinal width; this may be due in some degree to pressure, for this vertebra is much distorted by having been squeezed against the proximal end of the wing-metacarpal which was lying upon it. These vertebræ are shorter and more robust than the cervical above described: they appear to be procœlous. The neural spines are much thickened, especially at their dorsal extremities. The neural arches slightly overhang the centra. The transverse process of the left side of the last cervical is preserved. It shows that the transverse processes were produced outwards, as far as those of the notarium which follow it. They are sent off from the anterior half of the centra. These processes underlie the prezygapophyses, which are produced anteriorly; they are situated at the base of the neural arches, in front of the neural spines. The postzygapophyses are directed backwards, and overhang the posterior end of the centrum, thus forming a space into which the prezygapophyses of the following vertebra enters. The hinder ventral border of the last cervical on the left side has a short, fairly strong, posteriorly directed process, free from the articular surface of the centrum, the hinder extremity of which probably possessed an extra articular facet (exapophysis) as in *Ornithostoma* (*Pteranodon*). An ovate pneumatic foramen lies under the lateral base of the neural arches.

The Notarium.

The notarium (Pl. XXXVIII, figs. 3, 4, & 5) consists of six anchylosed vertebræ. The neural spines are fused into one strong ridge, which, above the first vertebra, is broader than the neural spine of the last cervical; it diminishes rapidly, until half as thick over the second, third and fourth, expands again at the fifth and sixth, where it is a third greater than at the anterior end, and becomes remarkably bulbous. There is no supraneural plate, and the surface of the bone shows no trace of such having come away. The dorsal outline of the fused spines is highest between the third and fourth vertebræ, as in *Ornithostoma*. The facet for the scapular articulation was probably beneath this, where on the right side there is a depression (Pl. XXXVIII, fig. 3, *fa.*), which,

however, is not seen on the left side; but this may be due to pressure. The neural arches overhang the centra, forming a ledge along the median region of their sides. The surfaces of these arches are alternately concave and convex in antero-posterior extent. The convexities occur where the zygapophyses have fused, and underneath these a series of fossæ are found (Pl. XXXVIII, fig. 5, *F.*, *F.*). Of these fossæ that of the first vertebra is the largest, the others decreasing in size to the last vertebra. Probably pneumatic foramina occur within the inter-vertebral fossæ, as they are not present elsewhere. On the dorsal surfaces of the transverse processes, the matrix is too hard, and they themselves are too fragile, to permit of its removal, and this is so likewise between the hinder three; but their ventral surfaces have been fully exposed. These processes arise partly from the neural arches, and partly from the centra. In the first notarial vertebra, as in the last cervical, they originate on the anterior half of the centra, and gradually extend more and more on each following vertebra, until in the fifth and sixth their bases occupy the length of the centrum. They are entirely free, one from the other, and are directed slightly upwards. They are arranged in three pairs, and each pair is different in size and form. The first pair are expanded at their bases and outer extremities, and contracted medially. The middle pair are weaker and shorter than the others, and their distal borders are produced posteriorly into a style-like process. The ultimate pair are considerably broader than the rest, are quadrate in shape, and are as long as the first pair. Their ventral surfaces are concave, with a curious downward turning of the anterior edge. This is also seen in the transverse process of the fourth vertebra. The spaces between the transverse processes are greatest between those of the first and second vertebræ; between the others they decrease, until between the last two the division has become narrow. The centra are comparatively small; their ventral surfaces are convex from side to side, and feebly concave longitudinally. The first three show a lateral concavity, the last are free from any grooving. On the hinder, lateral, ventral borders of the centra of the first three vertebræ, at their point of union, occur protuberances; these I take to be parapophyses.

The Dorsal Vertebræ.

The dorsal vertebræ are six in number and amphiplatyan. They decrease very rapidly in dimensions backwards. The neural spines are thinner, not so high, and the neural arch less expanded than in the notarial vertebræ. The transverse processes, instead of occupying a horizontal position, as in the vertebræ of the notarium, at once begin to assume an upright one, until in the fourth they are nearly vertical. The centra are convex from side to side; but, through the raising of their anterior and posterior edges, they are longitudinally more or less concave.

The Sacrum.

Unfortunately, only the fused centra of three, and a portion of the fourth, sacral vertebræ are preserved. They gradually lessen in dimensions posteriorly. The bases of the transverse processes are all that remain, and it is impossible to determine the form of the sacrum.

Vertebral Ribs.

Vertebral ribs were lying among the bones near the notarium. They were much waterworn. They are short, small, and hollow, and are two-headed as in other Ornithosaurs.

The Sternum.

There is no styliform anterior process of the sternum (Pl. XL, fig. 3) such as in all other types is greatly prolonged anterior to the coracoid facets. The keel is as remarkably developed as in the carinate birds. The anterior border is almost vertical; although, ventrally, it bulges slightly in front of the coracoid articular facets. The longitudinal outline rises posteriorly with a sharp curve, and has a greater length than depth. At the posterior end it is a little blunted, by the breaking-away of the rind of the bone. It is very robust, especially at the anterior end. In the lateral median region it becomes gently concave. The base of a strong bony process occurs near the centre of each lateral border, and appears to have been produced upwards and dorsally to them. Although the edge of the lateral expansion is broken away, the converging surfaces of the bone are divided by so narrow a space that they could not have been produced more than a fraction farther. Through this the costal facets are not seen. If they were present, they could only have occupied 18 mm. of the edge, for the rest of the border is too thin and angular for the sternal ribs to have articulated there. The dorsal surface is concave. There is a broadening of the fore part of the keel for the coracoid facets, which are placed below the sternal plate (Pl. XL, figs. 3 & 4, *cor.ar.fa.*). The right coracoid facet is situated 20 mm. below the sternal plate and 42 mm. above the ventral outline of the keel. In Seeley's figure of this sternum [1] the coracoid facets are incorrectly depicted as being on the same plane as the lateral expansions. The facets are oblique, the right ventral to the left. They were continued on to the lateral surfaces of the keel: ventral to each is a well-developed wing of bone, preventing dislocation of the coracoids. At the posterior termination of each of these is a cavity, determined by Seeley to be pneumatic foramina. This may be so, but they are also cavities into which the hinder point of the distal articular end of the coracoids entered when the movements of the wings caused these bones to be at their utmost posterior limit, the walls of these cavities acting as stops. The articulations are pulley-joints. I estimate the true length of the sternal plate to have been 65 mm., and the breadth 44 mm. A restored outline, of half the natural size, is given in Pl. XL, fig. 5.

[1] 'Dragons of the Air' 1901, fig. 67 & p. 175.

The Appendicular Skeleton.

The Pectoral Girdle.

The scapula and coracoid are strong bones. The former is shorter than the latter. The scapula is fused to the coracoid; the line of suture is horizontal, and both bones here are truncated. Only the preaxial half of the proximal end of the scapula is in union with the coracoid, and here it is bulbous; whereas the free portion is compressed dorso-ventrally, and set at right angles to the glenoid cavity. Its articular surface looks downwards, and forms an extra glenoidal surface (Pl. XXXVIII, fig. 7, *ad.ar.sur.*). The articular surface of the fused portion is oblique. The glenoid cavity is saddle-shaped. The dorsal surface is convex and the ventral flat, but both become concave near the glenoid cavity. The bone here shows a quadrangular section. The preaxial border immediately behind the glenoid cavity is deeply emarginate, followed by a strong convexity (the acromion process), and that again by a concavity to the distal end. The postaxial border is very concave over its whole length. The distal extremity is considerably expanded; the vertebral margin has a concave facet, apparently for articulation with the notarium. The postaxial border of the proximal end of the coracoid is bent downwards into a kind of lip with a convex articular surface. The coracoid is moderately curved. It is expanded at both ends pre-postaxially and compressed in the central region of the shaft, the preaxial edge traversing postaxially across the bone, until at the sternal end it is in the centre of its ventral surface, which gives the appearance of a twist to the bone. Its sternal articular face is concave pre-postaxially, with its preaxial border produced distally more than the postaxial. Anterior to the glenoid surface of the coracoid there is a triangular inarticular portion, the apex forming the border of the bone. It is produced into a tubercle, between which and the scapula is a groove, which leads into a pit or pneumatic foramen, situated at the base of this triangular area, near the articulation.

The Humerus.

The proximal condyle of the humerus is of the usual Ornithosaurian character, feebly convex on its articular surface, and crescent-shaped in outline, with the horns well splayed out. Near the dorsal border of the preaxial side of the articular surface of the condyle is a strong ridge. The deltoid crest is remarkably developed. It springs powerfully from the preaxial border, at some distance below the head, and curves spirally round the bone until its apex is over the middle of the ventral surface of the shaft. This spiral curve commences 40 mm. from the proximal condyle, and terminates 125 mm. from it. Along its outer curve it measures 75 mm. At its distal end it is 27 mm. above the surface of the shaft. This extremity is claw-like, the point directed postaxially,

quite different from those of the other genera where the distal end is more or less obtuse. The ulnar crest is moderately developed. Between the deltoid and ulnar crests the ventral surface of the bone is concave, but becomes convex as soon as the radial crest is passed. The shaft gradually decreases in size until, in the median region, it has a diameter of 22 mm.; from here it rapidly expands to the extremity, where its pre-postaxial diameter is 64 mm. The bone here is triangular, the apex being on the median line of the dorsal surface. Immediately underlying the apex on the articulation there is a large circular opening into the shaft (Pl. XXXIX, fig. 3, *f.*). A similar vacuity is found in many of the humeri included in the genus *Ornithocheirus* of the Cambridge Greensand. On the preaxial side of this opening is a small, feebly-convex, triangular surface, on which the preaxial moiety of the proximal end of the ulna articulated. Ventral to it is a moderately developed trochlear joint, oblique, looking outwards, and forming the articulation for the radius (Pl. XXXIX, fig. 3, *tr.*) On the postaxial side of the central opening is a deep valley (*v.*), which traverses the ulnar condyle diagonally, from the ulnar tubercle to the central pit. The ulnar tubercle is produced distally; it is strong and claw-like, with a concave side facing the articulation. Two strong ridges border the valley, the upper of which rises vertically from the bottom of the valley, while the lower has a sloping face. The dorsal border of the distal end over the upper ridge is much compressed, buttressing the ridge, and making it appear as if the edge of the bone had been doubled over. The distal articular extremity is beautifully preserved in the Atherfield specimen No. 1 (Pl. XXXIX, fig. 3); and the proximal ends of the radius and ulna (Pl. XXXIX, fig. 4) are in a like condition. The median area of the dorsal surface at the distal end is much inflated, and slightly concave at the pre-postaxial borders. A very strong epiphysis (Pl. XXXIX, fig. 2, *ep.*) overlapping the bone is present on the preaxial border of the ventral surface. It formed a support to what must have been a very large tendon, which was inserted in a deep cavity under the inner condyle of the trochlear joint for the radius. This pit is separated by a broad convex ridge from another, situated near, but postaxial to, the median line of the bone. A large pneumatic foramen is present in this cavity. On the postaxial border of the ventral surface, and nearer the distal end than the one on the preaxial, is a ridge (Pl. XXXIX, fig. 2, *ri.*), the distal termination of which does not follow the border, but passes inwards on to the ventral surface. The ridges and valleys of the distal ventral surface give a sigmoid outline, proximally to which the bone becomes convex. The postaxial border of the distal end is remarkably robust, and produced outwards from the long axis of the bone; while the preaxial is parallel to it. A restoration of the right humerus is given in Pl. XXXIX, fig. 2.

The Radius.

The radius (Pl. XXXIX, figs. 5 & 6, *R.*) is slightly shorter than the ulna, and very much less in diameter throughout its length. Proximally, it is ventral to the ulna, and placed on the preaxial side. From here it gradually rises and crosses over the shaft of the ulna, until the distal end is entirely dorsal to it, and occupies the central half of the ulna, the remaining quarters of that bone being visible on each side. The proximal articulatory surfaces fit the trochlea on the preaxial ventral border of the distal end of the humerus. Proximally, the radius is compressed dorso-ventrally and expanded pre-postaxially. Its dorsal surface is convex, while the ventral is concave, and convex on its pre-postaxial border. The last-named quickly becomes an angular ridge, which is continued distally for a short distance; then the whole bone becomes circular and rod-like, until it approaches the distal end, where it gradually expands pre-postaxially. The distal articular end is a simple convex pulley. On the postaxial side of the dorsal surface of the distal end there is a well-developed longitudinal ridge, and the striæ made by the fibres of a muscle traversing the bone from the preaxial border are visible. On the ventral surface contiguous to the postaxial border there is a longitudinal groove.

The Ulna.

The ulna (Pl. XXXIX, figs. 5 & 6, *U.*) is a very powerful bone. In the median area of the shaft it has a diameter three times greater than that of the radius. The shaft is straight, but an expansion of both articular ends gives a somewhat curved outline to the pre-postaxial borders. The proximal end (Pl. XXXIX, fig. 4) is roughly triangular, the apical side being on the dorsal surface. There is no olecranon. On the preaxial side of the articular surface is a triangular area, in extent equal to a third of the articulation: this is weakly convex, obliquely placed, and looks ventrally. The remaining two-thirds of the articulation constitute a platform, which is raised above the other third and looks distally. In the centre of this space is a high and strong **V**-shaped ridge (Pl. XXXIX, fig. 4, *R.*) with the angle directed postaxially. The ventral branch articulates in the valley (Pl. XXXIX, fig. 3, *v.*) on the distal end of the humerus. Thus the overlapping dorsal edge of the humerus enters between the two branches, where they converge at the angle. On the dorsal side of the angle of the **V** is a shallow concavity, in which the tubercle of the ulnar condyle of the humerus rests, and acts as a stop to any dislocation in a preaxial direction, as the angle of the **V** does in the opposite. Along the postaxial half of the **V**, and ventral to it, is a curved groove, in which the convex ventral border of the postaxial side of the humerus articulates. A pneumatic foramen is present in the centre of the ventral surface of the shaft, near the articulation. Distal to this is a high robust ridge (Pl. XXXIX, fig. 6, *ri.*),

extending some distance down the bone. The crown of the ridge is highest near its distal termination, and its top bends over, forming on its preaxial side a slightly-concave surface, against which the radius rested. The section of the bone here, *minus* the ridge, is circular, gradually becoming oval in the median region of the shaft, and this in its turn gives place to a quadrangular section as the distal end is approached. At the distal end the bone is expanded pre-postaxially: the dorsal surface is flat, the ventral concave, and the pre- and postaxial borders convex, although these surfaces have raised and concave areas. On the dorsal surface, towards the postaxial border, is a longitudinal ridge (Pl. XXXIX, fig. 5, *ri.*): against it the radius lies, and is thus supported and stiffened by a ridge on the postaxial ventral surface of the proximal end, and also by a similarly-placed ridge on the dorsal surface of the distal end. On the ventral side, near the postaxial border at the distal extremity, is a circular facet (Pl. XXXIX, fig. 6, *fa.*) with a flat articular surface raised above the bone, placed obliquely, looking preaxially, and continuing distally to a convex condyle on the articulation. This forms a very prominent feature. The preaxial border is very deep; 40 mm. from the distal end its dorsal margin is produced into a wing, which, rapidly expanding outwards, extends to the distal end: here the whole border is swollen, and terminates in a tubercle directed distally and moderately produced. By this arrangement, on the distal preaxial border an elongated concavity is formed; this has a roughened surface, and forms the insertion for a powerful tendon.[1] The postaxial distal border is convex, and is not expanded outwards to as great an extent as the preaxial. As at the proximal end, the distal extremity comprises the whole of the pre-postaxial extent of the articulation. Here the radius articulates dorsally to the ulna. On the articular surface of the distal extremity, postaxially to the tubercle, a deep, circular, basin-shaped pit occurs; this is followed by a trochlear joint extending to the postaxial border. The inner condyle of this trochlea is an oval-shaped convexity, situated medially, with its long axis directed pre-postaxially. The convex outer condyle is continued obliquely on to the ventral surface of the shaft, where it looks preaxially.

The Carpus.

The carpus consists of three distinct bones—a proximal, a distal, and a lateral carpal. The proximal and distal carpals are much wider than long, and the lateral longer than wide. The proximal articular surface of the proximal carpal is greater in area than the distal, causing the outer face of the bone on all sides, more or less, to slope inwards, towards the distal articulation; in the distal carpal this feature is reversed, and thus there is a constriction towards

[1] For the guidance of future students of this specimen, I may mention that this area of the right ulna was accidentally excavated too much when the bones which covered it were being freed from the matrix.

the proximal articulation. All the surfaces of the carpals are very complex. The preaxial border of the proximal carpal is produced outwards into an elongated process of bone, truncated at its extremity. This has on its proximal surface a spherical knob of bone (Pl. XXXIX, fig. 8, *A*), which articulates in the circular pit on the distal articulation of the ulna (Pl. XXXIX, fig. 7, *A*). The dorsal surface of this process is concave, and here occurs a subcircular pneumatic foramen. This surface articulates apparently with the lateral carpal. From this preaxial process on the ventral side the bone narrows, first showing a convexity followed by a concavity, afterwards enlarging considerably in a proximal and postaxial direction to the border. This expansion (Pl. XXXIX, fig. 8, *C*) articulates with the convex condyle of the distal end and the circular facet on the ventral surface of the ulna (Pl. XXXIX, fig. 7, *C*, & fig. 6, *fa.*), and in a proximal and distal direction is produced for the length of the distal carpal, articulating with it on its inner face. The dorsal preaxial border is remarkably raised proximally into a strong buttress, which juts out as a wedge-shaped piece of bone, anchylosed to the carpal. The butt-end of this wedge has a concave groove, in which the radius articulates (Pl. XXXIX, fig. 8, *D*). From this buttress to the postaxial border the bone narrows, and the surface is mainly convex, without any peculiar feature. A process similar to that on the proximal carpal occurs on the preaxial border of the distal, directed also preaxially, and possessing, on its proximal surface, a facet for articulation apparently with the distal end of the lateral carpal. On its preaxial dorsal half, for the same distance as the buttress for the radius on the proximal carpal, the bone is produced outwards and distally in such a manner that the two form a deep quadrangular cavity. Whether a sesamoid bone occupied this hollow it is not possible to say; however, it is suggestive, for such have been found near this point in the German specimens. The postaxial half of the dorsal surface is nearly flat. The bone gradually expands from the preaxial to the postaxial border, which is produced distally outwards. The postaxial border is the apex of an angle, formed by the conjunction of the ventral and distal articulatory surfaces, which gradually converge together to this point. The articulation for the radius on the proximal carpal is an elongated groove, parallel to, and near, the dorsal surface, and midway between the pre-postaxial borders (Pl. XXXIX, fig. 8, *D*). That for the ulna is much more complex (Pl. XXXIX, fig. 8, *A*, *B*, *C*). It consists preaxially of a hemispherical knob (*A*). dorsal to which is a small concavity (*E*); postaxial and ventral to the knob is a large basin-shaped concavity (*B*), followed by a ridge, and that again by a concave surface (*C*), having its postaxial, and a portion of the ventral, margin so raised that its articular surface is oblique to the main articulation. This surface comprises the postaxial moiety of the articulation. The knob (*A*) fits into the pit or socket on the preaxial side of the distal end of the ulna (Pl. XXXIX, fig. 7, *A*). The concavity (*B*) articulates with the

convexity on the distal end of the ulna (Pl. XXXIX, fig. 7, *B*), and the raised surface of the concave postaxial surface of the articulation (Pl. XXXIX, fig. 8, *C*) articulates with the circular facet on the ventral surface near the postaxial border of the ulna (Pl. XXXIX, fig. 6, *fa.*); while the rest of the concavity articulates with the convexity on the postaxial extremity of the ulna. The distal articulation of the proximal carpal, and the proximal of the distal carpal cannot be seen, as the bones are cemented together by matrix; yet, so close are they in all perceptible characters to some of those from the Cambridge Greensand, that no doubt can be entertained as to the similarity of their articulations.

The distal articulation of the proximal carpal, as seen in the Cambridge specimens, comprises two transverse concave surfaces divided by a ridge, the dorsal one being only half the extent of the ventral. The smaller is oblique, looking outwards, and the larger distally; but, as it terminates at the distal end of the wedge-like prolongation on the postaxial edge of this carpal, it becomes raised here, and also looks outwards.

The proximal articular surface of the distal carpal has convexities corresponding to the concave surfaces of the distal end of the proximal carpal. Thus a trochlear joint is formed, with a prepostaxial movement. The distal articulation of the distal carpal is beautifully seen in the Atherfield specimen No. 1. Nearly in the centre of the articulation is a very large and deep circular pit (Pl. XXXIX, fig. 9, *D*), the diameter of which is 17 mm. Dorsally to this is an elongated, narrow, shallow and concave, articular surface, placed obliquely, so that it looks both upwards and distally (*C*). This takes no part in the articulation with the wing-metacarpal; it is dorsal to it, and on a different plane. The small metacarpals articulated here. On the preaxial side of the central cavity and ventral to that just described, is a triangular area, the ventral angle of which is continued round the central pit; ventrally to this the bone expands, and then narrows and extends as a curved bar to the articulation for the small metacarpals, and thus the central cavity is completely bounded. All these surfaces slope inwards, forming a socket (Pl. XXXIX, fig. 9, *B*) in which the main proximal end of the wing-metacarpal articulated. In addition to these surfaces there is a quadrangular articular facet (Pl. XXXIX, fig. 9, *A*) below the plane of the others, and more proximal, also for articulation with the wing-metacarpal (Pl. XXXIX, fig. 10, *A*); but, as will hereafter be shown, not during flight, as that would have been impossible, and to perform an entirely different function. The lateral carpal is a small shovel-shaped bone, but may have approximated closely to the American forms in life, as it is slightly waterworn on the side on which the emargination occurs in those genera. It is longer than wide, and has a depth of about half its length. It fits in between, and presumably articulates with, the two elongated processes thrown out, on their preaxial borders, by the proximal and distal carpals.

The Metacarpal.

The proximal end of the ulnar metacarpal is well seen in the Atherfield specimen No. 1 (Pl. XXXIX, fig. 10); and the distal is fairly well seen in the Atherfield specimen No. 2. Its exact length cannot positively be determined, for a portion of the shaft is missing. If we judge from the great size of the proximal end and the much reduced distal extremity, and produce their borders at the required angles to connect them, its length would seem to be about 215 mm.,[1] or roughly half that of the ulna: this is far from what it should be, if it followed the structure of the short-tailed forms, where the metacarpal is not shorter than the antebrachium. However, in *Ornithostoma*,[2] which is short-tailed, 'the bones of the forearm [are] . . . shorter than [the] wing-metacarpal.' The proximal end is remarkably robust, and occupies the full width of the distal carpal articulation. From the preaxial side, the articular surface is convex for two-thirds of its extent; this is followed by a deep valley. Postaxially to this, is a flattened oval facet (Pl. XXXIX, fig. 10, *A*), which does not look proximally as the others do, but has its ventral edge raised and the dorsal depressed, so that its articular surface is oblique to them, and looks outwards and upwards. Half of its area lies outside the line of the postaxial border of the bone, although that border branches out and supports it. When the two-thirds are in articulation with the distal carpal, this facet is free, and thus takes no share in the joint. It articulates with the flattened oblique facet, proximal to the main articulation of the distal carpal on the dorsal surface of that bone (Pl. XXXIX, fig. 9, *A*), and then only when the metacarpal is directed backwards, and is rotated in a postaxial direction. Such a position would be assumed in folding the wing. The distal articulation is an obliquely-placed trochlea; it is very similar to the examples of this end of the metacarpal from the Cambridge Greensand, figured by Owen and Seeley. The dorsal and preaxial borders of the bone are moderately convex. The dorsal surface at the proximal end possesses a deep concavity on each side, and a convexity in the centre, which gradually dies away distally. The proximal lateral borders of the bone are much raised, especially on the preaxial margin. Within this area (Pl. XXXIX, fig. 10, *C*), the splint-like small metacarpals were situated; their position is above the plane of the ulna, and in the same line as the radius. The small metacarpals are only preserved as fragments; the proximal end of one is lying in the concavity on the dorsal surface of the wing-metacarpal. It is a very small rod-like bone, with a little thickening at the articular end pre-postaxially, and a convex articular surface. Their number is not known.

[1] As before mentioned, the bones of the Atherfield specimens are equal in size.

[2] S. W. Williston, 'Restoration of *Ornithostoma (Pteranodon)*' Kansas Univ. Quart. ser. A, vol. vi (1897) p. 51.

The Pteroid.

The right pteroid (Pl. XXXVI, fig. 1, *pt.* & Pl. XL, fig. 1) was lying parallel to the radius, with its proximal end overlapping (15 mm.) the radius and over the position of the lateral carpal. The last-named bone had become displaced. The pteroid is of the usual whip-like form. It has a flattened expansion at its proximal end, tapers to a point at the distal, is hollow, of small size, and a fourth of the length of the antebrachium. The dorsal border of the expansion is convex, the ventral is compressed and flat. The outer surface has pronounced longitudinal muscle-striæ; the inner is a very shallow concavity, in the centre of which is an oval foramen 9 mm. long and 4 mm. wide.

The Wing-Phalanges.

All the wing-phalanges are hollow. The portion preserved of the right first phalange (Pl. XL, fig. 2, *W.ph.*) is 330 mm. long. The general form of the bone is of the usual type. The proximal articulation is three times the diameter of that of the centre of the shaft. The articular surface for the ulnar metacarpal is concave, and extends along the ventral half of the bone. Immediately dorsal to this occurs the usual epiphysis, which is more pointed, and directed to the dorsal side, than in other forms. Lying externally to this, and occupying the space between it and the dorsal border, there is a small and deep semicircular emargination (Pl. XL, fig. 2, *sc.e.*), bordered on the dorsal edge by an outgrowth of the bone, directed dorsally. In this a small rod-like bone (Pl. XL, fig. 2, *s.b.*) is placed and perhaps articulated. Both right and left first wing-phalanges possess this bone. The proximal end of the right first wing-phalange preserved in the B.M. R/176 specimen has two small, round, splint-like portions of bones, abutting against the dorsal half of the articulation.

The Second Wing-Phalange.

The second wing-phalange (Pl. XXXVI, fig. 1, *2 w.ph.*) seen in the Atherfield specimen No. 1 is not entire, on account of the missing section. Both articular ends are expanded. There is a great variation from the other wing-phalanges in the form of the shaft; the bone is triangular, the apex being on the dorsal border; the preaxial and ventral surfaces are concave (the latter more so than the former), and the postaxial convex. It soon passes into this form at the proximal end, and as quickly resumes the normal shape at the distal. This peculiarity is not occasioned by crushing. The bone is much thicker than that in other parts of the skeleton.

The Third Wing-Phalange.

The portion recovered of this phalange (Pl. XXXVI, fig. 1, *3 w.ph.*) is 127 mm. long. It is convex dorsally and ventrally, and concave pre-postaxially.

The Fourth Wing-Phalange.

No trace of this wing-phalange has been found.

The Pelvic Girdle.

The Ischium.

The ischium (Pl. XL, fig. 6) is a deep, thin sheet of bone. The dorsal border is produced in front of the acetabulum. The posterior end sends up a spur, which comprises the lower portion of the posterior margin of the acetabulum. On the anterior ventral border of the plate of the ischium is a fissure determining the extent of the fused pubic bone. No foramen is discernible.

Prepubic Bone.

No prepubic bone has been discovered.

The Femur.

The femur (Pl. XL, fig. 7) is long, straight and slender. Both extremities are robust, and the median region of the shaft is attenuated. The head and neck are terminal to the shaft, and the former is hemispherical. There is a large trochanter and a deep trochanteric fossa.

The Tibia.

A portion of the proximal end of the right tibia (Pl. XXXVI, fig. 2, *ti*), 115 mm. in length, is lying with its postaxial border exposed, between the quadrates. The articular surface is moderately concave, with little elevation of its margins. . The proximal end is moderately robust. The postaxial surface is concave, and the other surfaces are convex. The perfect bone probably almost equalled the femur in length. It is hollow, but the bone is thicker than the bones of the wing. Another portion of a limb-bone (Pl. XXXVI, fig. 2, *ti*), which I take to be also a part of a tibia, lies across the right quadrate and the proximal end of the right tibia. If it be the distal end of the same tibia, it must have been broken before petrifaction. There is no trace of a fibula.

Summary of the Characters.

Skull large, somewhat bird-like, cranium not arched longitudinally, no backward projecting occipital crest, occiput concave and reptilian, muzzle elongated. Length of skull = 560 mm.; mandibles = 420 mm. The alveolar border ends in front of the nares and 28 mm. behind the symphysis. Number of teeth, 24 in the upper, and 25 in the lower jaw, all lancet-shaped, compressed laterally, and interlocking. Posterior teeth larger than the anterior. The last tooth of the upper jaw overlaps the lower, and the last two of the lower fit into slots in the upper jaw. All the teeth

are placed vertically. No rising of the alveolar rims. Anterior nares large, oblique, looking outwards, near the tip of the muzzle, and separated from the antorbital vacuity. The antorbital vacuity is the largest fossa in the skull, and not confluent with the orbits. Orbits very small, circular, and placed far back in the head. Orbital rim incomplete. No sclerotic ring. Infratemporal fossa oblique, extending both in front and behind the orbits. A sixth vacuity (infra-orbital) occurs under, and confluent with, the orbits. The beak, anterior to the nares, and the brain-capsule are the only portions of the skull that are completely encased in bone. Dorsal bar ridging nares and antorbital fossæ, triangular, with no lateral expansion. The jugal is entirely separated from the supra-temporal arcade, and the jugal and quadratojugal from the infra-temporal arcade. The jugal forms merely a small moiety of the anterior border of the orbit, and is connate, at its lower extremity only, with the quadratojugal and quadrate. The jugal, quadratojugal, and quadrate are directed obliquely backwards; all connect with the maxilla. The quadrates articulate with the lower jaw, far in advance of the orbits, by plain pulley-joints. The lower temporal arcades are formed entirely by the quadrates. Length of symphysis = 70 mm. Six vertebræ in the notarium; no supra-neural plate. The transverse processes are free from each other; the anterior and posterior pairs are of the same length, the median shorter and smaller. Six free dorsal vertebræ. Sternum with a greatly developed bird-like keel, but no anterior spine-like projection. Little lateral expansion of the sternal plate. The coracoid articular facets overlap, and are prolonged on to the lateral surfaces of the keel. Radial crest of the humerus spiral, and directed distally. Humeral articulation with the ulna a compact hinge-joint; with the radius a well-developed trochlea. Radius much smaller than the ulna, and extremely attenuated in the median region of the shaft. Radius decussating the ulna, passing from a ventral preaxial to a complete dorsal preaxial position. Head and neck of femur terminal.

III. Mechanism of the Skull and Joints, and Movements of the Limbs.

The skull is beautifully adapted to combine strength with lightness. It is a mere framework of triangles, either in section, laterally, or at the base. It is constructed entirely on the cantilever principle. One end of the cantilever carries the beak and the other the brain-case, with the fulcrum at the mandibular articulation. The position of the teeth at the tip of the long jaws is mechanically bad, as with the tension on the back of the skull, exerted by the necessarily powerful neck-muscles, combined with the weight and strain of any large prey struggling in the jaws, the beak would tend to break midway between the tip and the fulcrum. To counteract this, the premaxillar bar is triangular and the maxillæ are band-like, with the wide diameter vertical. These bones are

hollow, and are supported and braced by the maxillo-nasal bars. A long muzzle would seem to have been more favourable for procuring food. The use of the teeth at the extremity of such a beak would be great if the diet consisted mainly of fishes and the smaller reptilia, and was seized in flight. The teeth are admirably fitted for that purpose, their interlocking gin-like arrangement being perfect for prehension, so much so that no prolongation of an occipital crest, as in *Ornithostoma (Pteranodon)*,[1] to permit of a greater development of the temporal muscles, was necessary. This was an adaptation for the same purpose by different means. Length of beak is seen in such birds as herons, storks, etc., which favour a like food, or as in the skimmer, *Rhynchops*, as mentioned by Dr. Eaton (*loc. cit.*). That the reptile dipped occasionally in the water in pursuit of its prey is likely, but the 'power of swimming,' which Buckland[2] thought that the Ornithosauria had, could not have been possible, for not only were the limbs included in the patagium, but the elbow-joint only allowed a hinge-like movement dorsoventrally, and the nature of the articulations of the carpus and the wing-metacarpal with the first wing-phalange precluded the backward motion required. The highly-developed keel of the sternum proves the reptile to have been of very powerful flight, and it is interesting to recall the opinion of Hermann von Meyer[3] with regard to the known Ornithosauria in 1859, that they could not have been migrating animals, because there was no keel. The evolution of the keel had been accomplished by the Wealden Period. The position of the coracoids in flight seems to have been at right angles to the keel, that is, with their articular ends on the coracoid facets of the keel opposite one to the other, and the scapulæ articulating with the dorsal vertebræ. The arc-shaped coracoid articular facets on the keel appear not to have been solely for purposes of flight, for the semi-revolution would weaken rather than strengthen the act, but to allow of the coraco-scapular arch being drawn forwards. The free articular portion of the scapula at right angles to the coracoid moiety of the glenoid cavity probably gave rotating freedom to the humerus in an antero-posterior direction, opposite to the supero-inferior movement in the act of flapping the wings. The ordinary saddle-shaped glenoid cavity permitted a much greater freedom of movement up and down, than from side to side; wherefore I suggest that the additional surface was primarily evolved to allow of the humerus being directed forward parallel with the long axis of the body, by a slight twist of the wings. Such a position was necessitated and assumed when the reptile was hanging from a rock or bough. During suspension the coracoids would also be drawn forwards, until their sternal ends overlapped one above the other as the peculiar coracoid articulations permitted. Those forms that possessed the coracoid

[1] G. F. Eaton, Mem. Connect. Acad. Arts & Sci. vol. ii (1910) p. 13.
[2] W. Buckland, Bridgewater Treatise No. 6, vol. i, 3rd ed. (1858) p. 218.
[3] C. E. H. von Meyer, 'Reptil. aus dem Lithogr. Schiefer d. Jura' 1860, p. 17.

articular facets looking 'dorsad and laterad' on an anteriorly-directed styliform process were certainly not adapted for this purpose, unless crushing has altered their position and extent.

The elbow comprised a compact hinge-joint, with perfect rigidity while the limb was used in flight, and, when necessary, complete flexibility. The strong buttress of bone formed by the doubling-over of the dorsal border of the distal articular extremity of the humerus seems to have originated through the great stress here during flight. The oblique ridge-like epiphysis on the proximal articulatory surface of the ulna articulated in the valley below the buttress, its dorsal face rested and was held under the ventral wall of the buttress, protecting the joint from upward dislocation. The claw-like postaxial condyle of the humerus, placed against the facet on the postaxial side of the ulna, prevented outward displacement, and the V-shaped ridge on the preaxial moiety of the articular surface of the humerus precluded inward shifting. Any upward, outward, or inward thrust at the elbow would not under ordinary usage disturb the joint. No rotating movement of the elbow was possible. Although the radius decussates the ulna no pronation or supination such as occurs in man was possible, for the human radius crosses in an anterior, while that of *Ornithodesmus* does so in a posterior direction; neither does the radius cross so far that its distal end reaches the opposite side as in man, nor is any rotatory motion possible, for it articulated with the proximal carpal in a deep transverse groove. Moreover, its flat ventral surface rested upon a similar surface on the dorsal side of the ulna. Such a flexibility would weaken, not strengthen the wing for flight. This decussation afforded a strut or support in the downward flap of the immense wings.

The folding of the wing was performed by the help of the three joints of the wrist and that of the wing-metacarpal with the proximal phalange. By the particular form of the ulnar articulation with the proximal carpal, the first joint had the power not only of a hinge-like motion dorso-ventrally, but also of a peculiar turn in a downward and backward direction. This was achieved by aid of the pit-and-ball articulation, and by the articulation of the postaxial articular surface of the ulna, on the ventral surface of that bone, with the raised ventral border of the proximal carpal. At the median joint (a trochlea) of the wrist the only movement possible was pre-postaxial, and thus the reverse of that of the elbow which was dorso-ventral. At the distal carpal and wing-metacarpal joint a rotatory motion was possible. On a turning and bending-back of the wing the two additional articular surfaces on these bones came into union, and continued the bend originated by the proximal joint of the wrist, in such a way that the carpus formed a sort of elbow enabling the wing-metacarpal and phalanges to take an upward position. By the aid of the distal wing-metacarpal and proximal phalange pulley-articulation, the distal portion of the wing could be carried at any inclination in a pre-postaxial arc. The arrangement of the first and second joints

of the wrist prevented either inward or outward dislocation. In all the forms the wing has been made to bend posteriorly from the wing-metacarpal and proximal phalange-joint, but this was not the case here. Dr. Plieninger[1] considers that in *Rhamphorhynchus kokeni* the chief articulation of the wing was less at the elbow and wrist, much more between the fifth metacarpal and wing-finger phalange; and Prof. Williston[2] thinks that in *Ornithostoma* there was very 'little movement in the wrist, considerable in the elbow, and very much in the shoulder.'

It would be interesting to know whether the robust longitudinal ridge (Pl. XXXIX, fig. 6, *ri*) on the ventral surface of the ulna, near the proximal end, occurs in many genera. Here, it appears, the biceps-tendon was attached, and not to the radius: for there is no tuberosity or cavity for its insertion apparent on the latter bone, if, indeed, it were not otherwise too weak to withstand the strain of flexing the lengthy limb with its patagium.

Both extremities of the ulna and the proximal end of the wing-metacarpal occupy the whole of the pre-postaxial diameters of the articulations, so that the wing was carried by the humerus, ulna, wing-metacarpal and phalanges, the radius only acting as a strut, and the small metacarpals and phalanges giving no assistance. Weak as are the small metacarpals, yet for all such purposes as suspension they would be sufficiently powerful to brace the manus in supporting the reptile, and their position, dorsal to the ulnar metacarpal, would be an aid to the grasp. Certain it is that the articulations of the wrist would permit the wing, when not extended, to be not only bent backwards parallel with the body, but also twisted inwards in a posterior direction, freeing it from all interference with the action of the other metacarpals. Prof. Williston thinks that, if *Ornithostoma* 'hung in the upright position when at rest, it is difficult to see where the head was stowed away' (*loc. cit.*). In *Ornithodesmus* it would have been easy for the head to be placed over or under the brachium, or drawn by the retraction of the neck on to the shoulders with the skull held upwards.

The femur, with its terminal head and neck, could only be carried at right angles to the long axis of the body, and its inclusion in the patagium made impossible anything but a sluggish forward and backward motion in ambulation. The bending of the leg to reach the ground took place at the knee-joint in a lizard-like manner. In recent reptiles and mammals, where the thigh is carried at right angles to the body, the neck and head of the femur are terminal or nearly so; and in birds and mammals, where it takes a vertical position, they are more or less at right angles.

[1] F. Plieninger, 'Die Pterosaurier der Jura Schwabens' Palæontographica, vol. liii (1907) p. 208.

[2] S. W. Williston, 'Restoration of *Ornithostoma (Pteranodon)*' Kansas Univ. Quart. ser. A, vol. vi (1897) p. 38.

IV. Morphology, and Comparisons with other Species.

The region between the snout and the occiput is highly modified, beyond all analogy with any known skull of the recent or fossil Reptilia. A straight dorsal outline of the beak is also found in *Pterodactylus*, *Campylognathus*, *Rhamphorhynchus*, *Ornithostoma*, and *Nyctosaurus*. In this respect *Ornithodesmus* varies from *Dimorphodon* and *Scaphognathus crassirostris*, where the beak is boldly convex, and approaches *Sc. purdoni*, where the beak has only a moderate convexity and is much more elongated. The concave reptilian occiput also closely resembles that seen in this species, and reminds one vividly of the Lacertilia, as, for example, *Lacerta ocellata* and *Varanus varius*, and the Rhynchocephalian *Hatteria punctata*.

The Nares.

The nares differ from those of other species in their greater area and close proximity to the extremity of the muzzle, although their position is posterior to the teeth. They are large, and situated near the end of the snout in *Dimorphodon*; but they are nearly vertical, and occur above the central lateral alveolar border. In *Scaphognathus crassirostris* they are smaller, and have the same inclination and position as in *Dimorphodon*. Like features obtain in *Sc. purdoni*, but they are farther from the tip of the jaws, and by their continuation behind the teeth approximate to *Ornithodesmus latidens*. In *Rhamphoryhnchus gemmingi* they are much reduced in dimensions, and terminate before reaching the last teeth. All these agree with *O. latidens* in having the nares separated from the antorbital fossæ by a long bar. In *Pterodactylus antiquus*, *Pt. kochi*, and *Pt. suevicus*, the nares occur some distance behind the teeth, and are confluent with the antorbital vacuities. In *Ornithostoma* and *Nyctosaurus* they are very small.

The Antorbital Vacuity.

The antorbital vacuity is greater in extent than, and dissimilar in form to, that of any other species.

The Antorbital Vacuity No. 2.

No Ornithosaur has anything approximating to the remarkable infra-orbital fossa of *Ornithodesmus latidens*. The extraordinary transposition of the bones that form its boundaries gives it a unique character. Apparently the origin of this vacuity is the closing-in of the bones surrounding pear-shaped orbits, as in *Dimorphodon*, leaving an opening below the eyes; but the form of the bones and their positions are quite different. In the latter the jugal is V-shaped, forming the anterior and lower boundaries; and the quadratojugal is triangular, comprising a moiety of the posterior border, and uniting with the supra-temporal arcade, both bones being vertical.

The Orbit.

In *Dimorphodon* and *Scaphognathus* the orbit is in front of the articulation of the quadrate with the mandible, and in *Pterodactylus*, *Ptenodracon* (Lydekker), *Rhamphorhynchus*, and *Nyctosaurus* the orbit is above that articulation. It is posterior in *Ornithostoma*, but in *Ornithodesmus* it is, relatively, more so. In the latter the orbit is widely removed from the anterior nares, which in *Ptenodracon* and *Ornithostoma* are in close proximity, much more separated than in *Pterodactylus*, and still more than in *Rhamphorhynchus*, *Scaphognathus*, and *Dimorphodon*. A great peculiarity is the extraordinarily-small moiety of the orbit formed by the jugal, and also that this should be in the anterior margin only—not below and behind, as would have been supposed by analogy with other species. So far as I am aware, there is no skull recent or fossil which has anything conforming to this. In 1870 Owen[1] remarked on the complete orbital rim, and that the lower border was mainly formed by the jugal. In *Ornithodesmus* the rays or outrunners thrown out by the jugal and quadratojugal over the infra-orbital vacuity apparently represent a vestige of a once complete orbit. The reduction in size and the alteration of the position of these bones have been caused by the elongation of the muzzle drawing these bones forward. In *Scaphognathus purdoni* the orbital fossa is the largest aperture in the skull, and the bones are arranged according to the plan of *Dimorphodon*. There is no closing-in of the bones that form their boundaries, but the modification which eventually produced this effect in *Ornithodesmus* was in progress.

The Supra-Temporal Vacuity.

The supra-temporal vacuity is greater in depth and more externally open even than in *Scaphognathus*, where it is deeper than in any other genus.

The Infra-Temporal Vacuity.

The extension of the infra-temporal vacuity, both anterior and posterior to the orbit, is another exceptional character. The nearest approach is found in *Pterodactylus antiquus*, where it lies obliquely below the hinder half of the orbit. It is interesting to note that it occurs before and beneath, but not behind, in the Dinosaur *Diplodocus*.

The Supra- and Infra-Temporal Arcades.

The exclusion of the jugal from the upper temporal arcade, the extension of the quadrate to the maxilla, and the squeezing-out of

[1] R. Owen, 'Foss. Rept. Liass. Form.' (Monogr. Pal. Soc.) 1870, pt. 3, p. 62.

the jugal and quadratojugal thereby are surprising characteristics and isolate *O. latidens* from every known family. Hermann von Meyer[1] describes the jugal of *Pterodactylus longirostris* (syn. *Pt. antiquus*) as forming the under and greater part of the anterior boundary of the orbit by a strong, pointed, outgrowing process. In *Pt. scolopaciceps* (syn. *Pt. kochi*)[2] he gives an almost similar plan; and the jugal in *Pt. crassirostris*[3] (syn. *Scaphognathus crassirostris*) he describes as a four-branched bone forming the under half of the orbits. Thus there is no arrangement approaching to that which obtains in *Ornithodesmus latidens*; but *Scaphognathus purdoni* reveals at least an incipient stage. Mr. Newton[4] says that the jugal in this species is 'a V-shaped bone,' and that the hinder branch 'has its posterior edge occupied by the quadratojugal.' Dr. G. Baur,[5] in some pertinent notes on Mr. Newton's paper, remarks that

> 'the tendency of the quadratojugal in *Scaphognathus* to separate the post-orbital from the jugal is very remarkable.'

This process of the exclusion of the jugal from the supra-temporal arcade is apparently an adaptive result. In *Ornithodesmus* the prolongation of the facial portion of the skull is about $5\frac{1}{2}$ times that of the cranial, and in *Pterodactylus antiquus*, the nearest to it in shape, $3\frac{1}{2}$ times; while in *Scaphognathus crassirostris* it is $1\frac{3}{4}$ times. This proportion in the two last-named permits of the vertical position of the jugal process, to meet the lachrymal; but in *Ornithodesmus latidens* the proportion of the length of the beak to that of the cranium is so much greater, that not only the jugal, but also the quadratojugal and quadrate have become elongated forwards, until the entire jugal, the greater part of the quadratojugal, and the quadrate are in front of the orbit. The posterior production of the maxilla to the quadrate has not originated this disposition of the jugal, for the position of the hinder extremity of the maxilla in *Pterodactylus* and in *Scaphognathus* is the same as in *Ornithodesmus*, namely, beneath the posterior third of the antorbital vacuity; and this is its location in *Pterodactylus antiquus*, *Pt. kochi*, *Pt. suevicus*, *Dimorphodon*, *Rhamphorhynchus*, and *Ornithostoma*: it cannot be directly for the reduction of the weight of the skull, for in *Dimorphodon* the maximum had almost been attained. It must be that the prolongation of the beak, which was more favourable to the reptile in procuring food, has drawn out and displaced the jugals, the quadratojugals, and the quadrates, to the extreme. The great length of the lower temporal arcades in antero-posterior extent is in striking contrast with their shortness in *Pterodactylus*, *Scaphognathus*, *Dimorphodon*, *Ptenodracon*, *Ornithostoma*, and *Nyctosaurus*.

[1] 'Reptilien aus dem Lithogr. Schiefer d. Jura' 1860, p. 27.
[2] *Ibid.* p. 33. [3] *Ibid.* p. 41.
[4] E. T. Newton, Phil. Trans. Roy. Soc. ser. B, vol. clxxix (1888) p. 505.
[5] Geol. Mag. dec. 3, vol. vi (1889) p. 173.

The Maxilla.

In *Pterodactylus*, *Rhamphorhynchus*, *Ornithostoma*, and *Nyctosaurus*, the jugal and quadratojugal intervene between the maxilla and the quadrate, or are situated in front of the articulation of these bones. In *Scaphognathus purdoni* both the jugal and the quadratojugal are some distance in advance of the articular end of the quadrate underlying the centre of the orbit, where the maxilla terminates. The quadratojugal is vertical and triangular, its comparatively-broad base completely shutting out the maxilla from the quadrate; but here is to be seen the initial stage of the union of the maxilla with the quadrate, which was finally attained in *Ornithodesmus latidens*.

The Nasal.

The nasals in *O. latidens* have on each exterior border of the sigmoidal ventral surface an eave-like edge, which is evidently the vestige of a once greater lateral expansion. In *Scaphognathus crassirostris* and *Dimorphodon macronyx* the nasals spread out as a roof over the antorbital fossæ. In *Scaphognathus purdoni* [1] their extent has been thought uncertain, as the bone has come away from the areas of their position. On a careful examination of the original specimen in the Museum of Practical Geology, Jermyn Street, London, I found that by the grooving and the direction of the striæ on the underlying matrix, the plan of the bones could be made out. The areas in question were not only covered by portions of the nasals and prefrontals, but also by the anterior ends of the lachrymals; and the singular fact of the bone having come away from two such symmetrical areas appears to be accounted for by the outline being determined by the thickening and strengthening of the bones forming the upper boundary of the orbit, the antorbital fossa, and the dorsal ridge of the beak. The premaxillary bar is seen to be produced to the frontal, separating the nasals. Where the latter unite with the premaxillæ a channel occurs. The nasals are comparatively large bones. The prefrontals by rising processes border the orbits and meet apophyses from the frontal, excluding the nasals from the orbits. The main portions of the prefrontals are wedge-shaped, and are produced forwards, terminating between the nasals and tongues sent out by the maxillo-nasal bars, on their union with the nasals. These maxillar processes are united ventrally to the anterior horns of the crescent-shaped lachrymals, which are situated in the upper corner of the antorbital vacuities, form moieties of the orbital rims, and meet the ascending branches of the jugals with their posterior horns. The fractured edges, and the markings on the matrix, appear to prove that the frontal does not reach as far as Mr. Newton suggests. He thinks that it separates the prefrontals from the orbits, but it

[1] E. T. Newton, Phil. Trans. Roy. Soc. ser. B, vol. clxxix (1888) p. 505.

does not apparently do this for more than 3 mm. anterior to the fracture. The nasals thus occupy their usual position interior to the prefrontals. Such being the case, they are situated as in *Scaphognathus crassirostris* and *Dimorphodon macronyx*.

The Quadratojugal.

The union of the quadratojugal with the maxilla, as has been pointed out by Dr. G. Baur,[1] is a character of the Sauropoda: he instances *Diplodocus*. It is seen in the Ornithopoda, for *Iguanodon* reveals a like arrangement, and also in the Amphibians *Chelydosaurus vranyi* (Fritsch) and *Dendrerpeton pyriticum* (Fritsch). The quadratojugals of *Dimorphodon macronyx* and *Scaphognathus purdoni* are triangular plates and placed vertically, and therefore differ from the quadratojugal of *Ornithodesmus latidens*. In *Rhamphorhynchus*, *Ornithostoma*, and *Nyctosaurus* they more or less approximate to this form.

The Quadrate.

Zittel[2] notes, as a character of the Pterosauria, that the inferior articular surface of the quadrate finishes in front of the middle of the orbit: thus, if we except *Ornithostoma*, where it is slightly in front, *Ornithodesmus latidens* is quite peculiar. The manner of the proximal union of the pterygoids with the quadrates of the European forms is as yet obscure, but there is not much doubt that distally it is effected in both *Scaphognathus* and *Ornithodesmus* by means of a rod-like bar from the pterygoids. The plain pulley-articulation of *O. latidens* is very different from the spiral groove of *Ornithostoma* (*Pteranodon*).

The Teeth.

The arrangement of the hinder teeth is unique. Several of the teeth of the upper jaws of *Dimorphodon* and *Scaphognathus* overlap the lower jaws. The teeth in *Pterodactylus antiquus* and *Pt. suevicus* occur much in advance of the nares, whereas in *Ornithodesmus* the nasal openings begin near the last teeth. In the former genus the teeth are short and conical, thus differing from the lancet-shaped teeth of *Ornithodesmus*. These lancet-like teeth are vertically placed, set in the alveolar border with great regularity, and these conditions, combined with their complete interlocking, constitute exceptional traits. The nearest approach is found in some of the fragments of jaws from the Cambridge Greensand that are included in the genus *Ornithocheirus*. In the type-specimen of *Scaphognathus purdoni* the alveoli appear to show that the teeth were slightly compressed laterally, and thus are nearer the dentition of *Ornithodesmus*.

[1] Geol. Mag. dec. 3, vol. vi (1889) p. 173.
[2] K. A. Zittel, 'Traité de Paléontologie' vol. iii (1893) p. 773.

The Notarium.

It is curious that in the process of development of a notarium *Ornithodesmus* should differ so much from *Ornithostoma* (*Pteranodon*). This is shown in the absence of the supra-neural plate and of the fusing of the extremities of the transverse processes by a band-like ossification. In *Ornithostoma* the scapular union took place on the supra-neural plate, and in *Ornithodesmus* on the fused neural spines. In the former, eight vertebræ comprise this compound bone; in the latter, six. In the former, the transverse processes of the first three vertebræ are fused with stout ribs; in the latter this feature is not seen. In *Ornithostoma* the transverse processes are of the same length; while in *Ornithodesmus* the median pair are shorter than the others. The reason of this is not apparent. The style-like process from the posterior side of the extremities of two of these may be an incipient stage of their fusion.

It appears from the notarium of *Ornithodesmus latidens* that the six anchylosed centra, described by H. G. Seeley as the sacrum of *O. cluniculus*,[1] belong to the notarium. Whether they belong to the notarium or to the sacrum, they are specifically separated from the former by the following characters :—the centra of the first and second vertebræ are comparatively flat and broad, with a pronounced longitudinal valley on the ventral surface of the third to the sixth, and the last four are broader and flatter than the first two. The valley is absent in *O. latidens*, and the ventral surfaces of all the vertebræ are convex from side to side and concave longitudinally.

The Sternum.

In *O. latidens* alone, among all known forms, is there a carina for the whole length of the sternum developed so highly, so arched, and with the lateral expansions so narrowed, as to approximate very closely to the similar structure in birds. It would seem that the expansion of the lateral plates decreases, as in birds, in ratio to the height of the keel. In *O. latidens* the position of the coracoid facets differs from that seen in birds. According to Seeley,[2] the articular surfaces ‘obliquely overlap, practically as in wading birds like the heron.’ In *Ardea cinerea*, as in all those birds that I have examined, whether in the fine series preserved in the Museum of the Royal College of Surgeons or elsewhere, the articular surfaces of the coracoids are situated not on the keel, but on the anterior boder of the lateral expansion, and separated in nearly all forms one from the other by bone. They must necessarily be oblique, for the lateral expansions are so. In the heron the extreme inner angle of one coracoid decussates over the other, and

[1] Q. J. G. S. vol. xliii (1887) p. 206.
[2] ‘Dragons of the Air’ 1901, p. 174.

both are wedged into the edge of the sternal plate in such a manner that they cannot move farther in an inward direction. Moreover, the articular surface is not produced beyond them, and thus absolutely prevents an inward, rotating movement past the keel. The only motion possible is an outward one, the sternal end of the coracoid sliding along in the articular groove, which has projecting edges to keep it in position. In *O. latidens* the mechanism is very different from that observed in *Ardea cinerea.* In lieu of an articulation in a straight line directed obliquely on the anterior margin of the sternal plate, we observe a semicircular free surface permitting an extraordinary rotatory movement of the coracoids around the anterior edge of the keel on to its sides; also it was possible for the sternal ends of the coracoids to decussate completely, and not, as in herons, only the inner third of the articular surface, which does not extend the full width of the bone. Dr. Plieninger [1] well shows how uncertain has been the knowledge of the exact position of the coracoid articulations; he points out that Goldfuss located them in two little fossæ on the dorsal side of the sternum, and H. von Meyer, in *Pterodactylus*, in a similar place, on the ground of the position of the coracoids. In *Ornithostoma*[2] and in *Nyctosaurus*[3] Prof. Williston says that they 'look dorsad and laterad.' The anterior process in both these genera projects in front of the sternum, and, being very close to that characteristic of the *Rhamphorhynchus* type, is therefore far removed from that of *O. latidens*. In the examples of the sternum from the Cambridge Greensand described by Seeley, the anterior outline of the anterior process is directed obliquely forward from the lateral expansions, not vertically as in *O. latidens*; and the form and position of the coracoid facets differ. Dr. Plieninger [4] has well described the form of the sternum of both long- and short-tailed forms. It is quite evident from my description and the figures (Pl. XL, figs. 3, 4, & 5) of *O. latidens* that it is impossible to include it within either of these two types. In the type-specimen of *Scaphognathus crassirostris* [5] the form of the sternum cannot be accurately determined, as it is lying under the flattened skeleton, and the aspect is therefore probably the dorsal. According to Hermann von Meyer,[6] the sternum appears as a broad rhomboidal shield with rounded ends. The sternum is not known in *Scaphognathus purdoni* or *Dimorphodon*.

All the specimens of other genera, where the sternum is well displayed, can be assigned without doubt either to the long- or to the short-tailed forms.

[1] 'Pterosaur. d. Jura Schwabens' Palæontographica, vol. liii (1907) p. 299.

[2] 'Restoration of *Ornithostoma* (*Pteranodon*)' Kansas Univ. Quart. ser. A, vol. vi (1897) p. 42.

[3] 'Osteology of *Nyctosaurus* (*Nyctodactylus*), &c.' Field Col. Mus. Publ. 78, Geol. Ser. vol. ii, No. 3 (1903) p. 139.

[4] *Op. supra cit.* p. 298.

[5] A. Goldfuss, Nova Acta Acad. Leopold.-Carol. vol. xv (1831) pt. 1, pls. vii & viii.

[6] 'Reptilien aus dem Lithogr. Schiefer d. Jura' 1860, p. 43.

The keel of the sternum of Ornithosaurs had apparently a totally different morphological origin from that of birds. Most authors have thought that the anterior spine is homologous with the interclavicle; some aver its homology with the episternum of crocodiles and the manubrium of birds. The facts certainly appear to prove that it is the interclavicle, primarily of dagger-like shape, and occupying, with its posterior end, the 'primordial cleft' of the sternum, and that the coracoids rested directly on the dorsal surface of the spine with the scapulæ arched in the primitive position towards the vertebral column. Under the influence of flight, the interclavicle became arched in front and gradually pushed backwards, until we find it in *Ornithodesmus* vertically at right angles to the lateral expansions, instead of on the same plane, and thus occupying the same position as the keel in birds. As the interclavicle bent posteriorly under the pressure, the coracoids worked their articular facets at first to look obliquely outwards and at last laterally, thus rendering possible movement from in front to the side, and bringing the free ends of the scapulæ into conjunction with the neural spines of the vertebræ.

There are several examples of the interclavicle retracting in a forward direction, until but a vestige remains—caused mainly, I believe, by the action of swimming, the limbs with their backward thrust stimulating the forward thrust of the ends of the coracoids, until they united, thereby squeezing out, as it were, the interclavicle. In the Ichthyosauridæ the coracoids are in conjunction behind, and separated in front by the interclavicle; and in the Plesiosauridæ the coracoids, with the exception of an anterior fissure, united through the greater part of their length. They only require the keystone of the interclavicle, which undoubtedly in an earlier ancestor, at least, divided both the pre-coracoids and the coracoids. In the Nothosauridæ the coracoids unite in the median line, without a cleft, the vestige of the interclavicle being found as a keystone at the united end of the clavicles, the 'omosternum' of Hulke. In birds the articulation of the coracoids on the grooved antero-lateral margins of the sternum is reptilian; while in Ornithosaurs it is on the interclavicle, which is neither reptilian nor avian, but ornithosaurian, and a unique modification.

The Shoulder-Girdle.

Scapula and Coracoid.

In *Scaphognathus*, *Dimorphodon*, *Pterodactylus*, and *Rhamphorhynchus* the shoulder-girdle is more primitive than in *Ornithodesmus*, *Ornithostoma*, or *Nyctosaurus*, lacking the high specialization of these genera, and more or less retaining a splint-like form. Remarkable variation in detailed characters is found in species of the same genus, as, for example, *Pt. suevicus* and *Pt. longicollum*. The main difference between *Ornithodesmus* and *Ornithostoma* and *Nyctosaurus* is the rather slender process in the two last-named described by

Prof. S. W. Williston [1] as found in the inner angle of the fused bones enclosing a foramen. He mentions, too, that a similar process and foramen are seen in a Cambridge Greensand example described by Owen,[2] who assigns this girdle to *Pterodactylus sedgwicki* (syn. *Ornithocheirus sedgwicki* Seeley sp.). Dr. Plieninger [3] also notes its occurrence in *Pt. suevicus.* The foramen seen in these specimens is clearly the remnant of a cleft that once existed between this process and the girdle, and there is much to be said for Prof. Williston's suggestion that it is 'possibly a vestigial clavicle.' If I understand correctly, the line of union between the scapula and the coracoid in *Ornithostoma* runs horizontally across the glenoid cavity. In that respect it is similar to *Ornithodesmus* and *Nyctosaurus*, and different from both these in the line being transverse and like a Cambridge Greensand example figured by H. G. Seeley.[4]

The Humerus.

The great development and spiral curve of the deltoid crest distinguishes *Ornithodesmus* from all other genera. The only humeri that I can discover which have a somewhat similar spiral curve, although in not so great a degree, are those from the Lower Chalk of Bluebell Hill, Burham (Kent), in the British Museum (Natural History), and numbered respectively R/1935 and R/1357. The very high specialization of the distal end cannot be compared with that of any known genus. The distal end of a humerus R/37 in the same Museum approximates to it. Distal ends of humeri from the Cambridge Greensand, in the Sedgwick Museum, show it in an incipient degree. The German forms, where the distal end can be examined, possess a trochlear joint with the radial condyle greater than the ulnar.

The large circular foramen on the articular surface of the distal end of the humerus of *Ornithodesmus* is certainly very curious. Possibly a synovial gland was located here. It is represented by a pit or depression in *Ornithostoma*.[5]

The Radius.

The remarkably reduced dimensions of the radius, when compared with the ulna, form a unique character. It is an interesting parallel modification with birds. The proximal articulation is more specialized, and consequently differs from the simple and almost flat articular face of the proximal end of the radius in

1 'Osteology of *Nyctosaurus* (*Nyctodactylus*), &c.' Field Col. Mus. Publ. 78, Geol. Ser. vol. ii, No. 3 (1903) p. 140; also 'Restoration of *Ornithostoma* (*Pteranodon*)' Kansas Univ. Quart. ser. A, vol. vi (1897) p. 43.

2 'Foss. Rept. Cret. Form.' (Monogr. Pal. Soc.) 1859, Suppl. i, p. 14.

3 'Pterosaur. d. Jura Schwabens' Palæontographica, vol. liii (1907) p. 268.

4 'The Ornithosauria' 1870, pl. i, fig. 10.

5 S. W. Williston, 'Osteology of *Nyctosaurus* (*Nyctodactylus*), &c.' Field. Col. Mus. Publ. 78, Geol. Ser. vol. ii, No. 3 (1903) p. 142.

other genera. Probably it will be found that the decussation of the ulna by the radius is not peculiar to *Ornithodesmus.* It certainly occurs among the Cambridge Greensand specimens. In the distal ends of the radius and ulna of *Pterodactylus compressirostris* from the Chalk Pit, Burham (Kent), which have been figured by Owen,[1] the radius is seen decussating the ulna. On the first plate the ventral, and on the second the dorsal, surfaces of both bones are exhibited. Seeley[2] has called attention to the fact that the fossil in fig. 1, pl. xxiv of Owen's 'Cretaceous Reptilia' is 'figured for the humerus' and, further, that 'the less well-preserved bone in that figure exhibits the ulna in its true position behind the radius': this, I think, should read, 'the radius in its true position behind the ulna.' In view of the similarity of the humeri from this chalk-pit, there cannot be much doubt that they belonged to the genus *Ornithodesmus.* In the reconstruction of the hand of *Rhamphorhynchus kokeni* by Dr. Plieninger, the distal end of the radius is partly behind the ulna, but in all other figures of restorations the radius is placed at its distal end parallel with the ulna. These reconstructions have been made from specimens in which the bones are compressed and displaced.

The fact that proximally the radius is in front of (ventral to) the ulna has long been known. As the distal end of the radius gradually worked into a dorsal position, either the proximal carpal expanded dorsally for the new articulation (the ulna by expansion at the distal end taking the place of the former radial articular surface), or at one period the radius articulated with a separate carpal, which, under the same influence, followed the radius, and became fused on the original dorsal surface of what is now the one proximal carpal bone. The latter, I think, was the case.

The radius and ulna are not separated in the central region of their shafts, as in birds.

The Ulna.

The ulna is more reduced in the median region of the shaft, more expanded at the extremities, and has more highly-specialized articulations than in any other known example. The proximal articulation is far removed from the trochlear joints of the European and American specimens; but some of the Cambridge Greensand specimens included in the genus *Ornithocheirus* exhibit it, although either in an incipient or in a degraded stage.

The Pteroid Bone.

Dr. Plieninger[3] says that, in the long-tailed forms, the pteroid is a short compressed rod, in the short-tailed forms slender and thin. *Ornithodesmus* possessed the type of the long-tailed forms.

[1] 'Foss. Rept. Cret. Form.' 1851–64 (Monogr. Pal. Soc.) pl. xxiv, figs. 1–2 & pl. xxx, fig. 5.

[2] 'The Ornithosauria' 1870, p. 45.

[3] 'Pterosaur. d. Jura Schwabens' Palæontographica, vol. liii (1907) p. 308.

In *Nyctosaurus*[1] the pteroid is greatly developed, and the proximal end on the lateral border has a wing-like projection at right angles to the shaft, which is not seen in *Ornithodesmus.*

As the question of whether the pteroid is the first digit or a separate ossification is still open, it will be as well to state what light is cast on the point by the study of *Ornithodesmus.* I have before stated that the proximal end was overlapping by 15 mm. the distal end of the radius. On its interior concave face there are no signs of muscle-striæ, while there are on the exterior surface lines converging proximally and apparently continued round the border of the bone, the whole appearance suggesting that the bone was affixed by muscular attachment. Moreover, the extreme proximal exterior surface is bevelled off, in such a manner that the edge is quite sharp; whereas, if articulating with the lateral carpal, it would at least be obtuse. The peculiar, large, oblong foramen on the inner surface is perhaps not pneumatic, but rather incomplete ossification for the adhesion of the investing tissue. Dr. Plieninger, in common with the majority of authors, believes the pteroid to be a turned-back thumb, as suggested by Hermann von Meyer. I agree with Prof. Williston (*loc. supra cit.*), that it is 'an entirely distinct ossification': because, if we concede that it is the thumb thrown back, we must explain how such a modification was accomplished. The thumb would assuredly be the first digit that would be used in clinging to rocks or boughs for support, and thus would have no incentive to reflex, as it would be, on account of the wing, the nearest and best digit to set in action for the grasp. We must suppose that both the 'thrown-back thumb' and the wing-finger were included in the patagium, leaving the intermediate digits free; and, if the former were reflexed, why not the latter? or, if the wing-finger be the fourth finger, as it would be if the pteroid is not the thumb, why is not the fifth finger found reflexed, as the pull would be as great on the one as on the other? According to this theory, the so-called 'pteroid' described an arc, until its present position was attained. There is nothing to prove that the wing-membrane was anything more than a fringe (if that) down the preaxial border of the arm, and this would not provide the powerful stimulus for so extraordinary a change: the stress would be so insignificant, that it cannot be conceived how it would be necessary as a stay, or as a means of stretching the narrow frill of the wing. Nor, in the position in which it is always found, nearly parallel to the antebrachium, could it enlarge or stiffen the spread of the wing in flight. What, then, are the causes which by their action produced such an effect? We have good reason for looking upon the 'pteroid' as an ossified extensor-tendon: for the enormous disrupting strain on this sinew by the weight of the lengthening wing-digit, when cleaving the air in flight, would set up an irritation within the tendon itself, which would cause ossification to take place. Thus, naturally, the end of the ossification farthest away

[1] S. W. Williston, Geol. Mag. dec. 5, vol. i (1904) p. 60.

from the place of attachment of the tendon would have a pointed whip-like extremity, by the gradual lessening of the stimulus towards the shoulder.

The Carpus.

The general form of the carpals approximates to those from the Cambridge Greensand, and therefore both to *Ornithostoma* and to *Nyctosaurus*; but, if these two are exactly similar to those of the Cambridge Greensand, then *Ornithodesmus* differs from them in sundry particulars.

The Metacarpals.

The length of the wing-metacarpal is intermediate between the long- and the short-tailed forms. In no other Ornithosaur yet discovered has the branching-out process on the postaxial border of the proximal articulation, with its separate articulation, been noted. The different figures of the type-specimens seem to show, and the restorations by various authors do exhibit, the small metacarpals parallel one to the other, as in all vertebrates, and not dorsal to the wing-metacarpal. I am convinced that, eventually, it will be proved that the latter was their position in many of the forms restored in the former way. I have found on the distal carpal specimens in the Sedgwick Museum the same articular surface for the small metacarpals as in *Ornithodesmus latidens.*

The Wing-Phalanges.

The much-reduced dimensions of the third phalange, compared with the second and first, seem to suggest that the shortening of the distal phalange was proceeding here, as in the American forms. The second wing-phalange has evidently been reduced in size to the limit of lightness, and the form is best fitted to combine this with strength. The small rod-like bone (Pl. XL, fig. 2, *s.b.*), which apparently articulated within the semicircular cavity on the proximal end of the first wing-phalange, may be a remnant of the fifth metacarpal. In fact, the wing-digit has been formed by the union of the fourth and fifth phalanges, and the thickening found at both the proximal and the distal ends of the wing-phalanges is the vestige of that union. It is at these extremities that this would be found, if anywhere: for the lessening in size of the bones for reduction in weight would take place in the middle of the shafts, after the anchylosis of the extremities. By this interpretation the structure of the manus of the Ornithosaur becomes simpler.

The Ischium.

The separation ventrally of the ischium from the pubis by a deep notch is not found in *Dimorphodon*, *Ornithostoma*, or *Nyctosaurus*, but agrees with that observed in *Pterodactylus*.

The Femur.

The terminal head and neck, the straightness of the shaft, its attenuation in the median region, and its length, separate the femur of *Ornithodesmus* from those of *Ornithostoma* and *Nyctosaurus.* In the two last-named the head and neck are placed at a slight angle to the shaft, which is shorter, stouter, and more curved than in the first-named. In the high development of the great trochanter it resembles *Ornithostoma.* The femur of *Rhamphorhynchus* differs in the robustness of the neck (which is nearly of the same size as the head), in the divergence of the neck from the shaft, in the comparatively-massive build of the proximal end, and in the shortness of the bone.

The femur of *Pterodactylus* resembles that of *Rhamphorhynchus* in the thick neck being set at an angle to the shaft, and in the undeveloped condition of the great trochanter; but it differs from that genus and approaches *Ornithodesmus* in the straightness and length of the shaft. The same thickness of the neck and inclination of the shaft are found in *Dorygnathus*, and apparently in *Dimorphodon* and *Scaphognathus*; although in *Dimorphodon* these characters are not well seen, for the head of the femur is lying within the acetabulum, and in *Scaphognathus* it is not well preserved enough to determine with accuracy. The femur of *Ornithodesmus* is separated by its terminal neck and head from any known genus of the Ornithosauria, and reveals a higher specialization.

V. Conclusions and Classification.

It is more than probable that, if the type-skulls of *Scaphognathus crassirostris* and *Dimorphodon* were not crushed, they would be found to possess the lizard-like occiput of *Ornithodesmus.*

Although the general outline of the skull reminds one of *Pterodactylus*, its structure differs quite fundamentally, for it is essentially similar to the plan of *Scaphognathus* and *Dimorphodon.* The separation of the nares from the preorbital fossæ is found in each. These skulls were increasing in lightness by the enlargement of the vacuities, and the reduction of their elements into thin bands and rods. The outcome of this adaptation was the severance of the jugal from the supra-temporal arcade, which in its genesis is seen in *Scaphognathus purdoni* and in its accomplishment in *Ornithodesmus latidens.* The triangular form of the jugal in the former had become an attenuated hollow rod in the latter, producing an incomplete orbit and an infra-orbital vacuity. The separation of the jugal, quadratojugal, and quadrate one from the other had also begun. The shape of the alveoli in *Sc. purdoni* proves that the teeth were semi-elliptical, thus approximating to the laterally-compressed form of *Ornithodesmus.* A vestige of the overlap of the teeth of *Sc. crassirostris* and *Dimorphodon* is found in *Ornithodesmus* in the last teeth of the upper jaw. The foregoing facts are strong evidence that the skull of *Ornithodesmus* is the highly-modified skull of *Scaphognathus.*

The confluent nares and preorbital fossæ of *Pterodactylus* caused by the degradation of the maxillo-nasal bar, and the reduction in dimensions of all the apertures of the skull in *Rhamphorhynchus*, show that their structure became modified in a direction opposite to that followed by *Ornithodesmus.* It is generally conceded that the skull of the recent *Sphenodon punctatus* is near the primitive type of the reptilian skull: *Scaphognathus*, *Dimorphodon*, and *Ornithodesmus* have retained its perforated character, *Pterodactylus* less so, and *Rhamphorhynchus* and *Ornithostoma* least. The modifications proceeding in these skulls were radically at variance. In *Pterodactylus* the maxillo-nasal bar had almost, if not entirely disappeared. It is said to exist in some examples of *Pt. elegans* (syn. *Pt. pulchellus*, according to Zittel), which demonstrates what had degenerated in the other species. How much significance can be attached to the small fragment of bone, hanging from the ventral surface of the posterior end of the premaxillar extension over the preorbital vacuities, cannot be decided. Hermann von Meyer thought it a prefrontal, which Dr. Plieninger[1] considers an attractive theory, but one that has yet to be proved. It may or may not be the vestige of the arch, but certain it is that the bars have disappeared or contracted. *Ptenodracon brevirostris*, a genus which must be included within the sub-order Pterodactyloidea, also retains the maxillo-nasal bar.

In *Rhamphorhynchus* the apertures were gradually closing in. In *Rh. longiceps*[2] the skull retained more of the open character than in any other species of this genus. The obliteration of the fossæ had proceeded farthest in the skulls of *Ornithostoma* and *Nyctosaurus* (syn. *Nyctodactylus*). In the latter the antorbital fossæ had become quite vestigial.[3] The tendency of most forms through time has been to reduce the size of the teeth, and lose the posterior dentition. In some species of *Rhamphorhynchus* the loss is seen to be in the reverse direction, commencing from the tip of the beak backwards. In *Ornithostoma* and *Nyctosaurus* the edentulous jaws prove that a final stage had been reached. Although there are only small moieties of the jaws to reason upon, I consider that the genera of the Cambridge Greensand belong to the Rhamphorhynchidæ. In some the teeth were retained, but the beaks were growing more attenuated and lance-like. In others the muzzle was retracting axially, causing the tip to deepen vertically and thicken laterally. The bold convexity of the dorsal outline and the depth of the beaks may suggest origin from *Scaphognathus*; but the extremely-light build of that skull could not have supported at its extremity so heavy a weight as the obtuse ponderous tip, without buckling. All these genera can be dismissed, as having no near affinity to *Ornithodesmus.* The latter is quite outside the genus *Ornithocheirus*: for, according to Seeley's amended definition of the genus, the characters are (i) teeth prolonged anterior to the muzzle, (ii) a

[1] 'Pterosaur. d. Jura Schwabens' Palæontographica, vol. liii (1907) p. 294.i,

[2] A. S. Woodward, Ann. Mag. Nat. Hist. ser. 7, vol. ix (1902) p. 4 & pl. fig. 3.

[3] S. W. Williston, Journ. Geol. (Chicago) vol. x (1902) p. 526.

longitudinal ridge on the palate. The typical dentigerous premaxillæ of the Cambridge Greensand in the Sedgwick Museum, although belonging to several genera, have been included in the genus *Ornithocheirus*, and endowed with the characters obtained from the fragments of bones; and also, on the discovery of the edentulous jaw, *Ornithostoma* with those pertaining to the American toothless forms. Thus Prof. Williston [1] remarks that not much remains to be known of the osteology of *Ornithocheirus*; whereas, in reality, nothing is known except the tip of the snout. Again, Dr. Plieninger,[2] following Williston, gives this classification:—

Family: Ornithocheiridæ. Orbit, preorbital, and nasal opening completely separated. Early dorsal vertebræ blended into the so-called notarium.

Sub-Family: Ornithocheirinæ. Scapula in union with the notarium. Sagittal crest to skull.

Genera: *Ornithocheirus*. Toothed.
Pteranodon. Toothless.

The only character obtained from the genus *Ornithocheirus* is 'toothed,' the family and sub-family characters are those of the genus *Ornithostoma* (*Pteranodon*).

Ornithodesmus is also generically distinct from *Ornithocheirus sagittirostris* (Owen).[3] The form of the teeth, the interspaces between them, their insertion in distinct alveoli with highly-raised rims, the length of the alveolar teeth, and the form of the rami, are quite different.

Ornithodesmus appears to have descended from a sub-order which should include *Scaphognathus* and *Dimorphodon*, necessitating the withdrawal of these two genera from the Rhamphorhynchidæ, and the formation of a new sub-order.

The three entirely varied phases of development in the skulls of Ornithosauria give a ready means of division into three sub-orders, as follows:—

Sub-Order: Scaphognathoidea.

Skull an open framework of bone, all fossæ very large. Nasal and preorbital vacuities separated. Concave lizard-like occiput.

Sub-Order: Pterodactyloidea.

Half the area of the skull encased in bone, all fossæ moderately large. Nasal and preorbital vacuities confluent. Convex bird-like occiput.

Sub-Order: Rhamphorhynchoidea.

Skull nearly encased in bone, all fossæ considerably reduced. Nasal and preorbital vacuities separated. Flat occiput.

In regard to the remainder of the axial and appendicular skeleton, the type-specimens are mostly crushed, fragmentary and so

[1] 'Osteology of *Nyctosaurus*, &c.' Field Col. Mus. Publ. 78, Geol. Ser. vol. ii, No. 3 (1903) p. 158.

[2] 'Die Pterosaurier der Juraformation Schwabens' Palæontographica, vol. liii (1907) p. 313.

[3] 'Foss. Rept. Mesoz. Form.' pt. i (Monogr. Pal. Soc.) 1874, p. 3 & pl. ii.

diversified in their nature, that the diagnosis of constant characters is rendered extremely difficult. The fusion of the dorsal vertebræ into a notarium in *Ornithostoma* and *Ornithodesmus* is absent in *Rhamphorhynchus*, *Pterodactylus*, and all other known types. The anchylosed shield-shaped sacrum is permanent throughout the sub-order Rhamphorhynchoidea, *Ornithostoma* and *Nyctosaurus* being of this type. In many of the examples of *Pterodactylus* the form of the sacrum is not definitely determinable. If all follow the type of *Pt. suevicus*, they possess a sacrum approaching the fused shield-like sacrum of the Rhamphorhynchoidea. Whether the sacral ribs in *Scaphognathus*, *Dimorphodon*, and *Ornithodesmus* are free or blended is yet obscure. The number of vertebræ comprising the sacrum is variable. In the Rhamphorhynchoidea the sacrum is avian, shield-shaped, with anchylosed ribs; and in the Pterodactyloidea it is avian or reptilian, with the ribs either free or anchylosed.

As fresh discoveries arise, we find that the division into long- and short-tailed groups is not a good one. *Scaphognathus crassirostris* has been placed in the long-tailed group by authors, as the wing-metacarpal is half the length of the antebrachium, and therefore *Sc. purdoni* has followed; but in neither is the tail known. Goldfuss restored the former with a short tail, and Zittel thought this correct. To the same sub-order Scaphognathoidea belong *Scaphognathus* with a short tail and *Dimorphodon* with a long; and to the Rhamphorhynchoidea, *Ornithostoma* and *Nyctosaurus* with a short tail, and *Rhamphorhynchus* with a long. In the Pterodactyloidea only short-tailed forms occur.

The form of the sternum in *Scaphognathus crassirostris* is uncertain, on account of the position and state of its preservation; and this element in *Sc. purdoni* and *Dimorphodon* is undiscovered. The sternum of *Ornithodesmus* is too highly specialized to provide any safe guide to the probable form of that bone in the two first-named genera.

The type of sternum of *Rhamphorhynchus*, with its strong anterior styliform process possessing no true keel, and the sternal plate a broadly-expanded shield with square anterior borders, is not only common to this long-tailed genus, but also to the short-tailed *Ornithostoma* and *Nyctosaurus*, therefore invalidating this type of sternum as a peculiar feature of the long-tailed group. In *Pterodactylus*, as exemplified by *Pt. suevicus*, there is an anterior spine, but no true keel; and the sternal plate is semi-elliptical, with its anterior borders rounded.

The scapula and coracoid in the early genera of the Scaphognathoidea were not fused; but later they became so, as shown by *Ornithodesmus*, and in the Rhamphorhynchoidea by *Ornithostoma*. In the Pterodactyloidea no genus is known in which these bones are anchylosed.

The humerus is crushed in all the type-specimens, and this may have had some effect in splaying out the deltoid crest: for probably in all it had originally a slight inward curve. Such a curve is seen

in a left humerus of *Ornithostoma* (*Pteranodon*).[1] In *Scaphognathus*, *Dimorphodon*, *Dorygnathus*, and *Pterodactylus* it spreads out as a wing from near the head of the bone. The two first-named have the superior border concave, and the two last-named convex and the wing deeper. In *Rhamphorhynchus*, *Ornithostoma*, and *Nyctosaurus*, the deltoid crest is placed near the proximal end of the humerus; it rapidly constricts, and broadens at the tip into a deeply-obtuse extremity. In *Ornithodesmus* it arises from below, and curves spirally downwards. We have thus four well-marked types. The species which come within these types are:—

Type of Scaphognathus:	Type of Pterodactylus:	Type of Rhamphorhynchus:	Type of Ornithodesmus:
Sc. purdoni (?)	*Pt. antiquus.*	*Rh. gemmingi.*	*O. latidens.*
Dimorphodon macronyx.	*Pt. suevicus.*	*Rh. muensteri.*	*O. cluniculus (?)*
	Pt. longicollum.	*Rh. kokeni.*	Humeri from the Lower Chalk of Burham (Kent) in the British Museum (Natural History).
	Pt. elegans (syn. *Pt. pulchellus*).	*Ornithostoma ingens.*	
	Pt. spectabilis.	*Nyctosaurus gracilis.*	
	Pt. medius.		
	Campylognathus zitteli.		
	Dorygnathus bathensis.		
	Ptenodracon brevirostris (?)		

The *Scaphognathus* type differs from the *Ornithodesmus* type: for the reason that we behold in *Scaphognathus* the beginning, and in *Ornithodesmus* the end, of a high specialization; to the same cause is probably due the fact that the deltoid crests of the humerus of *Campylognathus* and *Dorygnathus* are closer to the *Pterodactylus* than to the *Rhamphorhynchus* type.

The bicipital crest of the early forms is prominently produced outwards, and in the later very much reduced: for example, in the Scaphognathoidea, *Scaphognathus* and *Ornithodesmus*; in the Rhamphorhynchoidea, *Rhamphorhynchus* and *Ornithostoma*.

All these genera, so far as can be discerned, possess trochlear joints at the distal articulation of the humerus, and nothing approaching the complicated specialization of this joint in *Ornithodesmus*.

The equal dimensions of the ulna and radius in the early examples did not persist; the radius gradually became the smaller, especially in the central region of the shaft. The proximal articulatory surface of the radius evolved from a general flat area to two concavities divided by a ridge, for the trochlear surface of the humerus. The distal articulation remained a simple pulley.

The decussation of the ulna by the radius will probably prove to be common to more than one genus: for instance, in some of the Cambridge Greensand, Chalk, and American genera.

The foramen which pierces the ischio-pubic plate of most species does not occur in *Ornithodesmus*.

[1] G. F. Eaton, 'Osteology of *Pteranodon*' Mem. Conn. Acad. Arts & Sci. vol. ii (1910) pl. xx, fig. 4.

The pre-pubic bones of *Scaphognathus* and *Ornithodesmus* were probably spatulate, as in *Dimorphodon.* If so, they differed from the fan-shaped form characteristic of *Pterodactylus*, and from the curved band-like form seen in *Rhamphorhynchus*, *Ornithostoma*, and *Nyctosaurus.*

The terminal head and neck of the femur and the straight shaft in *Ornithodesmus* separate it from all other genera, where the head and neck are more or less inclined away from the shaft, which was more or less curved. In late forms the great trochanter became very robust.

The bones of the foot in most of the type-specimens are either imperfectly preserved, or not discovered.

The widely-divergent characters of *Ornithodesmus* from all known types make it necessary to form a new family, the Ornithodesmidæ. I offer, as best denoting our present knowledge, the following classification :—

I. Sub-Order : **Scaphognathoidea.**

Skull an open framework of bone, all fossæ very large. Nasal and preorbital vacuities separated. Concave lizard-like occiput.

Family : Scaphognathidæ.

Skull short, not produced into a rostrum. Jugal V-shaped, and united with the supratemporal arcade. Dorsal vertebræ not fused into a notarium. Sacral ribs not anchylosed. Long or short tail. Deltoid crest of humerus wing-like, with the superior border concave. Wing-metacarpal shorter than half of the forearm. ? Pre-pubic bones spatulate.

Sub-Family : Scaphognathinæ.

Short tails.

Genus : *Scaphognathus.*

Sub-Family : Dimorphodontinæ.

Long tails.

Genus : *Dimorphodon.*

Family : Ornithodesmidæ.

Skull elongated. Six lateral fossæ present. Orbits incomplete. Jugal separated from the upper, and the jugal and quadratojugal from the lower, temporal arcades. Maxilla united with the quadrate, without the intervention of the jugal or the quadratojugal. The last tooth of the upper jaw overlaps the lower jaw, and the last two of the lower fit into slots in the upper. Notarium present, consisting of six vertebræ. No supra-neural plate. The first and last pair of transverse processes are equal in length, the median pair shorter, all distally unanchylosed. Sternum with a large median keel, no anterior spine-like projection, a small lateral expansion of the sternal plate, coracoid articular facets overlapping each other and prolonged on to the lateral surfaces of the keel. Deltoid crest of humerus spiral. Radius decussating the ulna distally. Wing-metacarpal equal in length to half of the forearm.

Genus *Ornithodesmus.*

Nares posterior to all teeth. Orbits far behind the quadrato-mandibular articulation. Teeth lancet-shaped, compressed laterally, vertically placed,

set with great regularity in the alveolar border, showing little variation in size, interlocking. Six free dorsal vertebræ. Humeral articulation with the radius a well-developed trochlea, with the ulna a highly-specialized hinge-joint dorsal to the radius. Shaft of radius very attenuated. Small metacarpals articulating with the carpus dorsally to the wing-metacarpal. Neck and head of the femur terminal, shaft straight.

II. Sub-Order: **Pterodactyloidea.**

Half the area of the skull encased in bone, all fossæ moderately large. Nasal and preorbital vacuities confluent. Convex bird-like occiput.

Family: Pterodactylidæ.

Skull bird-like, with a long or short muzzle. Dorsal vertebræ not fused into a notarium. Sacral ribs free *(Pt. antiquus)* or anchylosed *(Pt. suevicus)*. Tail short. Sternum semi-elliptical, with an anterior spine. Scapula and coracoid separate. Humeral crest wing-like, with the superior border convex. Wing-metacarpal greater than half the length of the ulna. Pre-pubic bones fan-shaped.

Genus: *Pterodactylus.*

Sub-Family: Ptenodraconinæ.

Skull short. Preorbital and nasal vacuities separated.

Genus: *Ptenodracon.*

III. Sub-Order: **Rhamphorhynchoidea.**

Skull nearly encased in bone, all fossæ considerably reduced. Nasal and preorbital vacuities separated. Occiput flat.

Family: Rhamphorhynchidæ.

Skull without a supraoccipital crest. Jaws toothed. Dorsal vertebræ not fused into a notarium. Sacrum a shield-shaped anchylosed mass, with foramina. Long-tailed. Sternum rhomboidal, anterior spine, no keel. Deltoid crest of humerus constricted medially. Wing-metacarpal less than half the length of the ulna. Pre-pubic bones band-like and curved.

Genera: *Dorygnathus.* *Campylognathus.* | *Rhamphocephalus.* *Rhamphorhynchus.*

Family: Ornithostomatidæ.

Skull with prominent supra-occipital crest. Jaws edentulous. Short-tailed. Scapula articulating with the notarium. Wing-metacarpal longer than the ulna.

Genus: *Ornithostoma (Pteranodon).*

Sub-Family: Nyctosaurinæ.

No supra-occipital crest to skull. Edentulous. Tail short. Scapula not articulating with the early dorsal vertebræ.

Genus: *Nyctosaurus (Nyctodactylus).*

No antorbital vacuity.

Family: Ornithocheiridæ.

Longitudinal ridge on the palate.

Sub-Family: Ornithocheirinæ.

Teeth prolonged anterior to the palate.

Genus: *Ornithocheirus.*

RECENT CLASSIFICATIONS COMPARED.

S. W. Williston.[1]		Felix Plieninger.[2]		R. W. Hooley.	
				Sub-Order:	Scaphognathoidea.
				Family:	Scaphognathidæ.
				Sub-Family:	Scaphognathinæ.
				Genus:	*Scaphognathus* Wagner.
				Sub-Family:	Dimorphodontinæ.
				Genus:	*Dimorphodon* Owen.
				Family:	Ornithodesmidæ.
				Genus:	*Ornithodesmus* Seeley.
Sub-Order:	Pterodactyloidea.	Sub-Order:	Pterodactyloidea.	Sub-Order:	Pterodactyloidea.
Family:	Ornithocheiridæ.	Family:	Pterodactylidæ.	Family:	Pterodactylidæ.
Sub-Family:	Ornithocheirinæ.	Genus:	*Pterodactylus.*	Genus:	*Pterodactylus* Cuvier.
Genera:	*Ornithocheirus.*	Family:	Ornithocheiridæ.	Sub-Family:	Ptenodraconinæ.
	Pteranodon (Ornithostoma).	Sub-Family:	Ornithocheirinæ.	Genus:	*Ptenodracon* Lydekker.
		Genera:	*Ornithocheirus.*		
			Pteranodon.		
		Sub-Family:	Nyctosaurinæ.		
		Genus:	*Nyctosaurus (Nyctodactylus).*		
		Sub-Order:	Rhamphorhynchoidea.	Sub-Order:	Rhamphorhynchoidea.
		Family:	Rhamphorhynchidæ.	Family:	Rhamphorhynchidæ.
		Genera:	*Dimorphodon.*	Genera:	*Campylognathus* Plieninger.
			Campylognathus.		*Dorygnathus* Theodori.
			Dorygnathus.		*Rhamphorhynchus* Meyer.
			Scaphognathus.		*Rhamphocephalus* Seeley.
			Rhamphorhynchus.	Family:	Ornithostomatidæ.
				Genus:	*Ornithostoma (Pteranodon)* Seeley. Marsh.
				Sub-Family:	Nyctosaurinæ.
				Genus:	*Nyctosaurus (Nyctodactylus)* Marsh.
				Family:	Ornithocheiridæ.
				Sub-Family:	Ornithocheirinæ.
				Genus:	*Ornithocheirus* Seeley.

[1] 'On the Osteology of *Nyctosaurus (Nyctodactylus)*, &c.' Field Col. Mus. Publ. 78, Geol. Ser. vol. ii, No. 3 (1903) pp. 158–59.

[2] 'Die Pterosaurier d. Jura Schwabens' Palæontographica, vol. liii (1907) p. 313.

VI. Measurements in Millimetres.

Breadth of the muzzle 25 mm. from the tip	40
Depth of the same at the same point	40
Breadth of the skull at the centre of the upper border of the orbits	36
Breadth of the skull at the posterior end of the maxillæ	99
Depth at the same point	83
Breadth of the cranial roof between the supra-temporal pits	16
Breadth of the skull between the centres of the squamosal bars.	90
Greatest breadth of the brain-capsule	58
Depth of the supra-temporal pits from the cranial roof to the squamosal bar	35
Depth of the occiput, summit to lowest outer angle of quadrate.	62
Width of the occiput across the foramen magnum	73
Commencement of anterior nares from the tip of the beak	95
Breadth at the same point	9
Breadth at 140 mm. from the tip of the muzzle (line of fracture).	20
Vertical diameter of the orbits	30
Antero-posterior diameter	38
Length of the infra-orbital vacuities	80
Greatest breadth of the same	12
Length of the infra-temporal vacuities	95
Breadth of the same	17
Distance of the quadrate articulation in front of the orbits	99
Depth of the same below the dorsal outline of the beak	89
Depth of the palate, below the dorsal outline of the beak, 51 mm. from the anterior border of the nares	28
Height above the ventral edge of the mandibles when the jaws are closed, 51 mm. from the anterior border of the nares	26
Length of the alveolar tract of the upper jaw	85
Length of the alveolar tract of the lower jaw	94
Length of the anterior teeth	8
Greatest breadth of the same	4
Length of the posterior teeth	7
Greatest breadth of the same	7
Length of the mandibular symphysis	70
Length of the centrum of a cervical vertebra	53
Width between the exterior borders of the prezygapophyses of the same	40
Width between the exterior borders of the postzygapophyses of the same	48
Length of the dorsal edge of the notarium	110
Length of the ventral edge of the same	105
Length of the centrum of the first dorsal vertebra	14
Length of the scapula, from the glenoidal cavity	90
Depth of the distal end of the same	23
Pre-postaxial diameter of the scapula: humeral end	40
Ditto: coracoid	33
Length of the coracoid	113
Antero-posterior diameter of the sternal end of the coracoid	27
Ditto, centre of shaft	6
Length of the humerus (proximal to distal condyle)	220
Pre-postaxial diameter of the proximal end of the same	51
Ditto, centre of shaft	22
Ditto of the distal end	64
Spiral curve of deltoid crest begins below the proximal articulation of humerus	40
Length of the same along its outer curve	75
Depth of the same from the distal point to the shaft of the humerus	27

Pre-postaxial diameter at the proximal end of the radius	30
The same at the distal end	38
The same at the centre of the shaft	7
Pre-postaxial diameter of the proximal end of the ulna	60
The same at the distal end	52
The same at the centre of the shaft	19
Length of the pteroid	96
Breadth of expansion at the proximal end of the pteroid	10
Length of the lateral carpal	25
Pre-postaxial diameter of the proximal carpal	49
Pre-postaxial diameter of the distal carpal	43
Length of the carpus	28
Pre-postaxial diameter of the proximal end of the wing-metacarpal	56
Length of portion of the proximal end of the first wing-phalange, Atherfield specimen No. 2	318
Dorso-ventral diameter of the proximal end	54
Dorso-ventral diameter of the distal end	44
Dorso-ventral diameter of the proximal end of the second wing-phalange	44
Length of the proximal portion of the third wing-phalange, Atherfield specimen No. 1	127
Length of the sternal plate	65
Breadth of the same	45
Length of the keel	70
Depth of the same	60
Depth of the ischium from the acetabulum to the anterior ventral angle	76
Length of the femur as preserved. (Distal end slightly water-worn, but showing thickening for the articulation.)	200
Pre-postaxial diameter of the centre of the shaft of the femur	9
Dorso-ventral diameter of the same	12

The following measurements have been obtained by accepting 89 mm. as the length of the missing block from Atherfield specimen No. 1 :—

Length of the skull	560
Length from the tip of the muzzle to the centre of the orbits	500
Length of the mandibles	423
Length of the radius	368
Length of the ulna	381
Length of the first wing-phalange	393
Length of the second wing-phalange	388
Estimated spread of wing, from tip to tip, and allowing for the natural curve ... about	5 metres.

I have much pleasure in acknowledging the ever-ready assistance in the preparation of this paper afforded to me by Dr. A. Smith Woodward, F.R.S., and Dr. C. W. Andrews, F.R.S.

Bibliographies are to be found in :—

E. T. NEWTON, 'On the Skull, &c. of *Scaphognathus purdoni*' Phil. Trans. Roy. Soc. ser. B, vol. clxxix (1888) p. 503.

K. A. ZITTEL, 'Traité de Paléontologie' vol. iii (1893).

F. PLIENINGER, 'Die Pterosaurier der Juraformation Schwabens' Palæontographica, vol. liii (1907) pp. 210–17.

EXPLANATION OF PLATES XXXVI–XL.

Plate XXXVI.

[The right-hand block in figs. 1 and 2 is here exhibited with the matrix removed at a different angle from the other block. This block requires a half-turn to put the portions of bones thereon in their true connexion with those on the other block.]

Fig. 1. Upper view of Atherfield specimen No. 1, partly cleared of matrix: *Sn.*, snout; *pr.b.*, premaxillar bar; *no.*, dorsal border of the notarium; *rb.*, rib; *sc.*, scapula; *hu.r.*, distal end of right humerus; *r.r.*, right radius; *u.r.*, right ulna; *hu.l.*, distal end of left humerus; *r.l.*, left radius; *u.l.*, left ulna: *p.cp.*, proximal carpal; *pt.*, pteroid; *la.cp.*, lateral carpal; *w.mc.*, proximal end of wing-metacarpal; *mc.*, portion of one of the small metacarpals; *1.w.ph.*, distal end of the first wing-phalange; *2.w.ph.*, second wing-phalange; *3.w.ph.*, proximal half of the third wing-phalange. B.M. R/3877. × about $\frac{7}{24}$.

2. Nether view of Atherfield specimen No. 1, partly cleared of matrix: *Sn.*, ventral view of snout; *mx.p.*, inner view of maxillo-nasal process; *mn.*, portion of the mandible; *Q.r.*, portion of right quadrate; *Q.l.*, portion of left quadrate; *c.v.*, cervical vertebræ; *no.*, notarium; *d.v.*, dorsal vertebræ; *h.r.*, right humerus; *u.r.*, right ulna; *hu.l.*, left humerus; *r.l.*, left radius; *u.l.*, left ulna; *sc.*, scapula; *p.cp.*, proximal carpal; *d.cp.*, distal carpal; *l.cp.*, lateral carpal; *w.mc.*, proximal end of wing-metacarpal; *Isch.*, ischium; *f.*, femur; *ti.*, portion of tibia. B.M. R/3877. × about $\frac{7}{24}$.

Plate XXXVII.

Fig. 1. *Sn.*, the snout, freed from the matrix: *p.*, premaxilla; *n.v.*, nasal vacuity; *mn.*, mandible. B.M. R/3877. × $\frac{1}{2}$.

2. Portion of the skull near the orbit: *O.*, orbit; *a.o.v.*, antorbital vacuity; *a.o.v.2.*, antorbital vacuity No. 2; *i.t.f.*, infra-temporal fossa; *pr.b.*, premaxillar bar; *J.*, jugal; *Qu.*, quadratojugal; *Q.*, quadrate; *mx.*, maxilla; *mn.*, mandible; *mn.a.*, mandibular articulation; *b.*, rounded boss of bone. B.M. R/3877. × $\frac{1}{2}$.

3. Left lateral aspect of the hinder portion of the cranium, as preserved in B.M. R/176: *O.*, orbit; *s.t.f.*, supra-temporal fossa; *i.t.f.*, infra-temporal fossa; *s.t.b.*, supra-temporal bar; *Qu.*, quadratojugal; *Q.*, quadrate; *M.*, matrix with a fragment of a limb-bone. × $\frac{1}{2}$.

4. Interior view of the right maxillo-nasal process: *mx.n.b.*, part of the maxillo-nasal bar; *mx.*, maxilla; *a.*, line of division between the upper and the lower jaw; *mn.*, mandible. B.M. R/3877. × $\frac{1}{2}$.

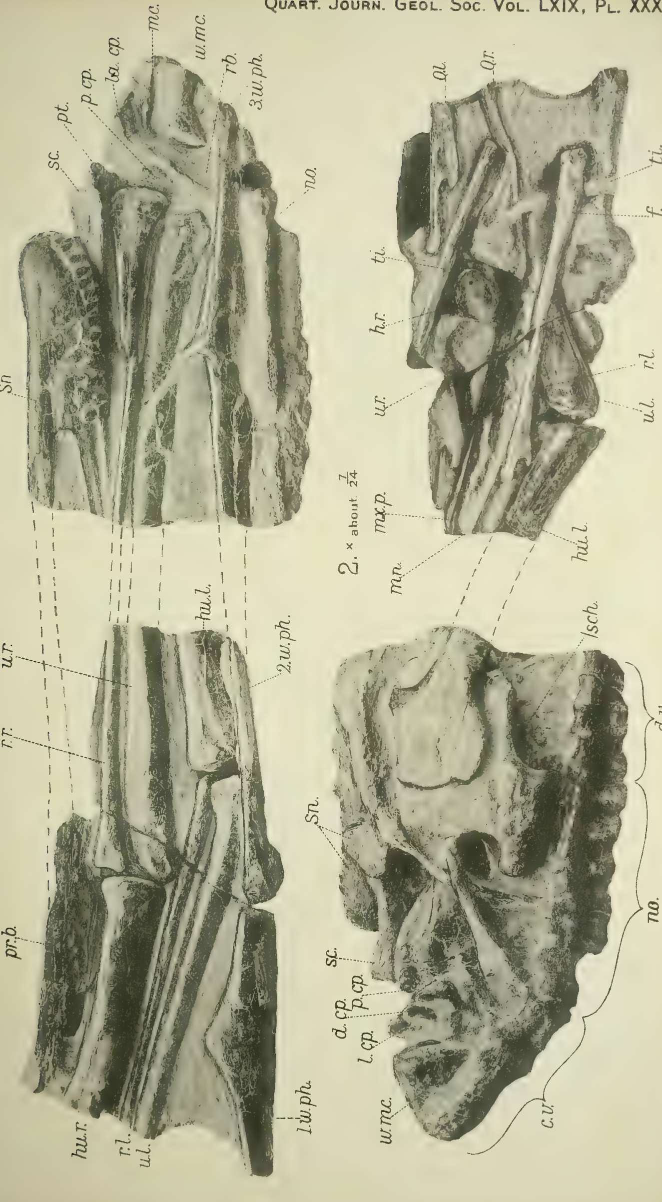
5. Restoration of the skull, perspective lateral view: *n.v.*, nasal vacuity; *a.o.v.*, antorbital vacuity; *a.o.v.2.*, antorbital vacuity No. 2; *o.*, orbit; *s.t.f.*, supra-temporal fossa; *i.t.f.*, infra-temporal fossa; *p.*, premaxilla; *mn.*, mandible; *mx.*, maxilla; *mx.n.b.*, maxillo-nasal bar: *J.*, jugal; *Qu.*, quadratojugal; *Q.*, quadrate; *s.t.b.*, supra-temporal bar; *p.f.o.b.*, post-fronto-orbital bar; *l.*, lachrymal; *b.*, rounded boss of bone. × $\frac{1}{5}$.

Plate XXXVIII.

Fig. 1. Restoration of the occiput: *p.t.f.*, post-temporal fossæ; *f.m.*, foramen magnum; *c.*, occipital condyle; *Q.*, quadrate. × $\frac{1}{2}$.

2. Restoration of a cervical vertebra, ventral view. × $\frac{1}{2}$.

3. Right lateral view of the notarium: *fa.*, the supposed articular facet for the scapula; *A*, anterior end. B.M. R/3877. × $\frac{1}{2}$.



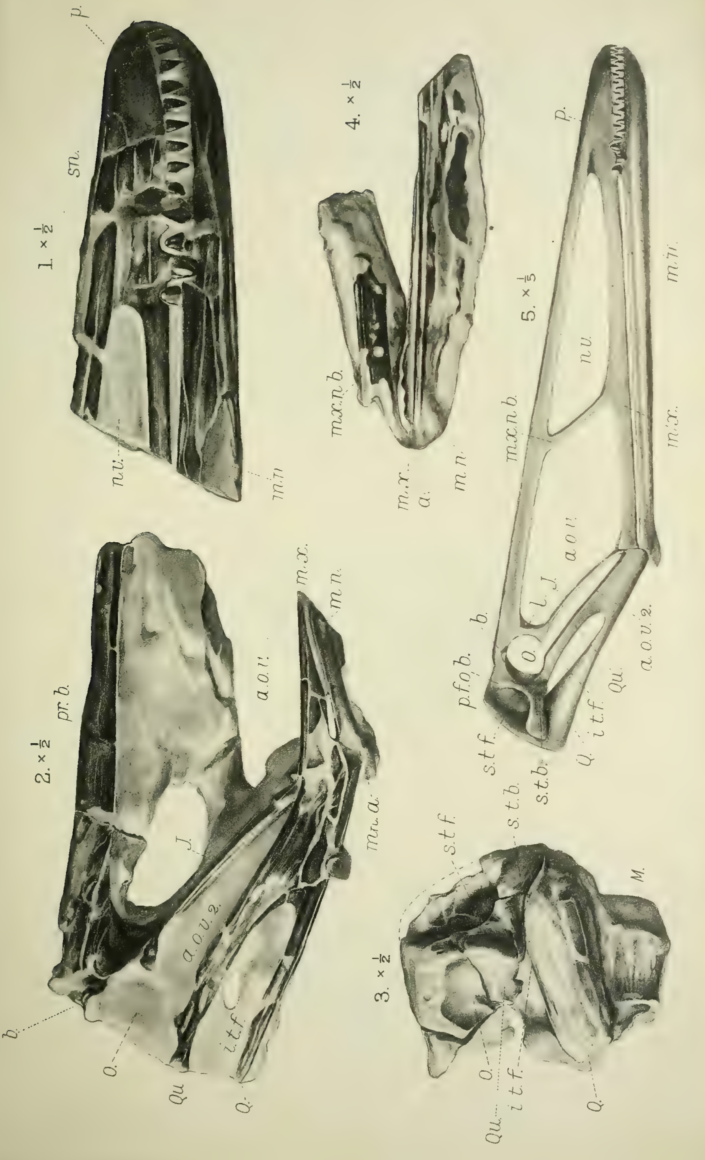
1. × about $\frac{7}{24}$

2. × about $\frac{7}{24}$

ORNITHODESMUS LATIDENS.

R.W.H. Photo.

Bemrose, Collo, Derby.



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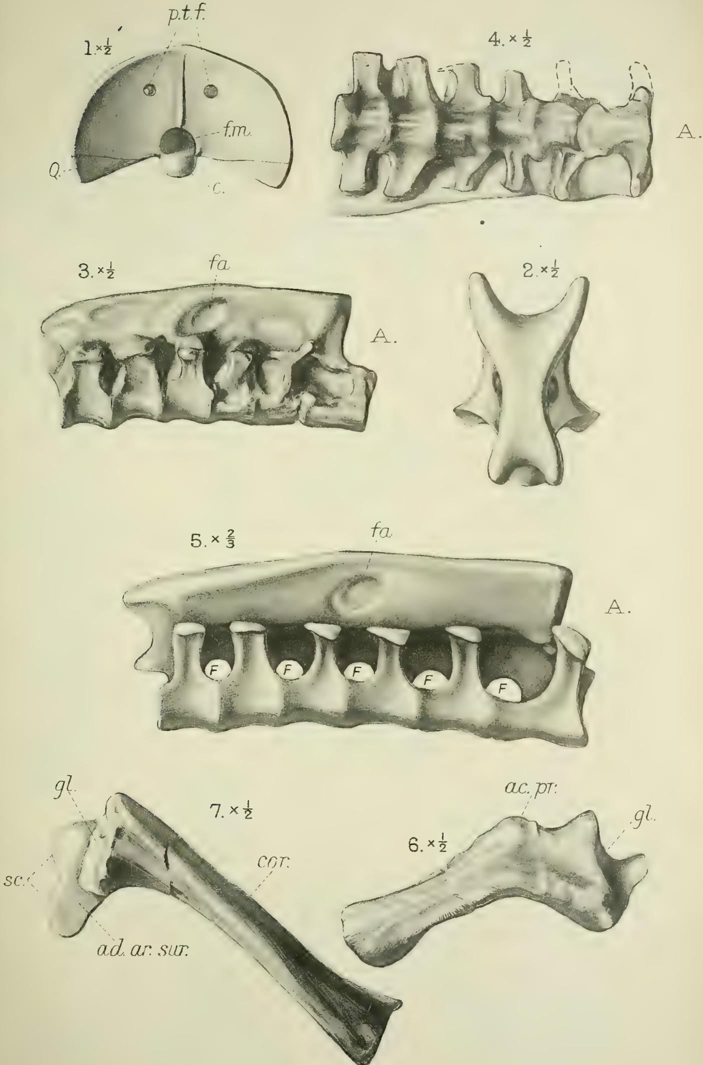

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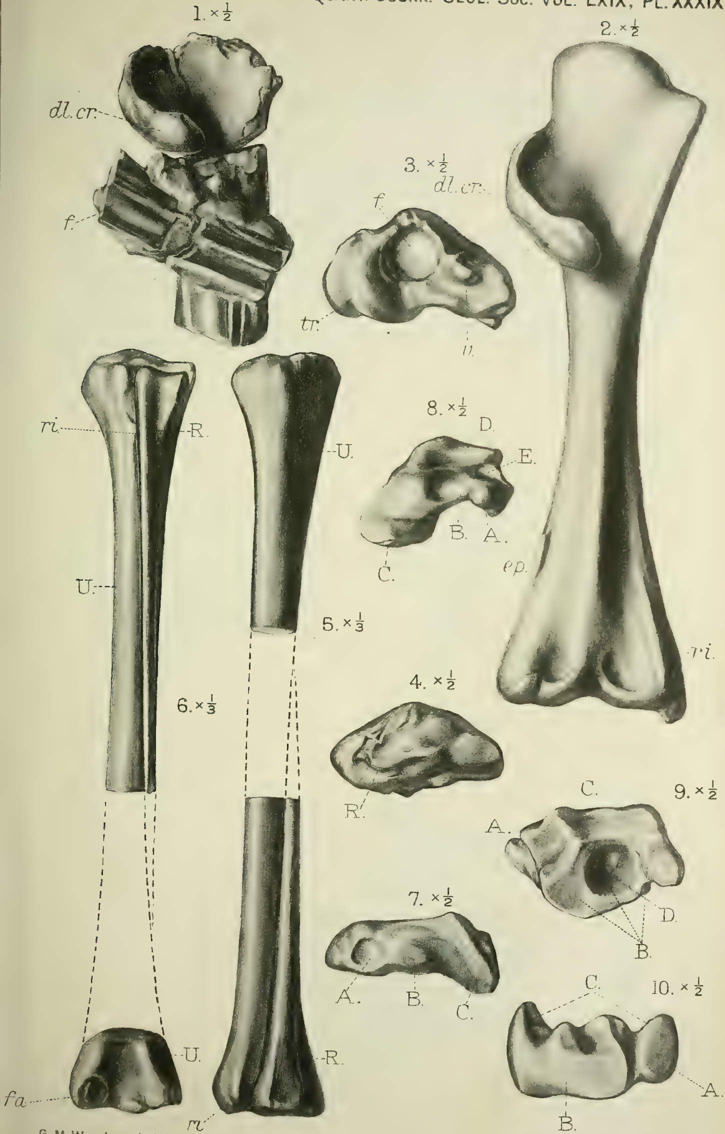

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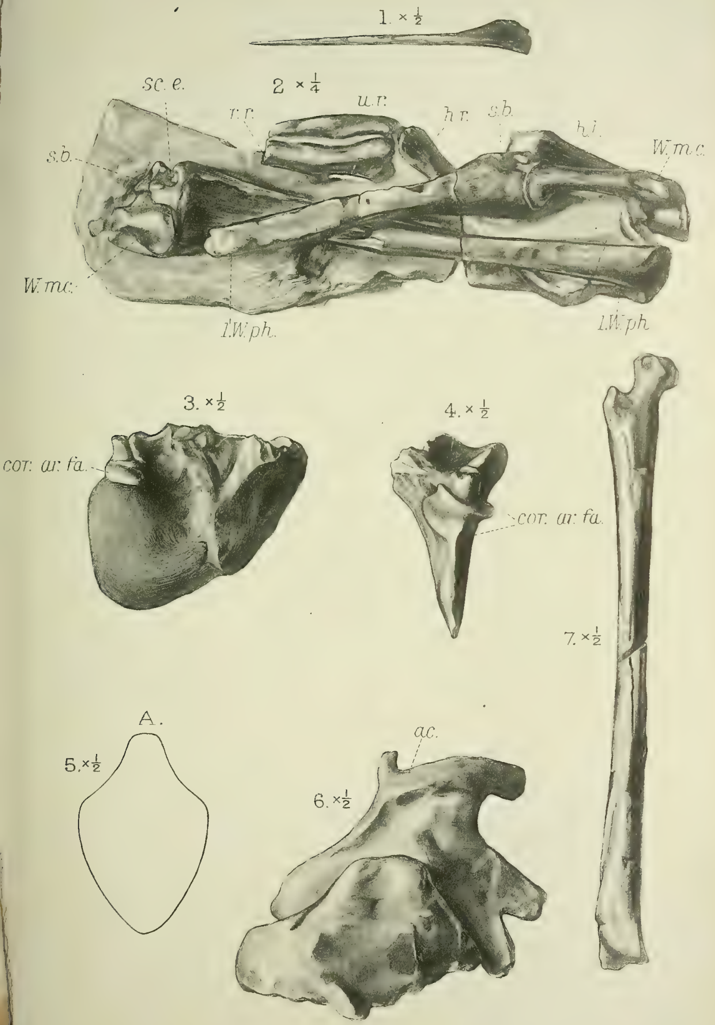

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Fig. 4. Ventral view of the notarium: *A*, anterior end. × $\frac{1}{2}$.

5. Restoration of the notarium, right lateral aspect: *F*, *F*, foramina; *fa.*, facet for the scapula; *A*, anterior end. × $\frac{3}{8}$.
6. Inner view of the left scapula, *minus* a moiety of the humeral end: *gl.*, glenoid cavity; *ac.pr.*, acromion process. B.M. R/3877. × $\frac{1}{2}$.
7. Humeral end of the right scapula and perfect coracoid: *sc.*, proximal end of scapula; *cor.*, coracoid; *gl.*, glenoid cavity; *ad.ar.sur.*, additional articular surface, placed at right angles to the glenoid cavity. B.M. R/3878. × $\frac{1}{2}$.

Plate XXXIX.

Fig. 1. Portion of the right humerus, exhibiting the spiral curve of the deltoid crest: *dl.cr.*, deltoid crest; *f.*, fragment of bone attached to the shaft of the humerus. B.M. R/176. × $\frac{1}{2}$.

2. Restoration of the humerus: *dl.cr.*, deltoid crest; *ep.*, an epiphysis overlapping the shaft; *ri.*, ridge for muscle-attachment. × $\frac{1}{2}$.
3. Distal articulation of the left humerus: *f.*, circular foramen into shaft; *tr.*, trochlea for the radius; *v.*, valley for the ulnar ridge. B.M. R/3877. × $\frac{1}{2}$.
4. Proximal articulation of the left ulna: *R.*, transverse ridge for articulation in the valley on the distal articulatory surface of the humerus. B.M. R/3877. × $\frac{1}{2}$.
5. Dorsal view of the right radius and ulna, showing decussation: *R.*, radius; *U.*, ulna; *ri.*, ridge. B.M. R/3877. × $\frac{1}{3}$.
6. Ventral view of the left radius and ulna: *R.*, radius; *U.*, ulna; *fa.*, articulatory surface articulating with the proximal carpal; *ri.*, ridge. B.M. R/3877. × $\frac{1}{3}$.
7. Distal articulation of the ulna: *A*, circular pit; *B*, oval convex condyle; *C*, articular surface prolonged on to the shaft of the ulna. B.M. R/3877. × $\frac{1}{2}$.
8. Proximal articulation of the proximal carpal: *A*, hemispherical knob; *B*, oval concavity; *C*, articular surface for articulation with that on the ulna marked *C* in fig. 7; *D*, elongate cavity for the radius; *E*, small concavity. B.M. R/3877. × $\frac{1}{2}$.
9. Distal articulation of the distal carpal: *A*, articular facet below the main articular surface; *B*, main articular surface; *C*, articular surface for small metacarpals; *D*, deep circular cavity. B.M. R/3877. × $\frac{1}{2}$.
10. Proximal articulation of the wing-metacarpal: *A*, articular facet below the main articulation; *B*, main articular surface; *C*, the position of the small metacarpals is within this space. B.M. R/3877. × $\frac{1}{2}$.

Plate XL.

Fig. 1. Right pteroid bone: B.M. R/3877. × $\frac{1}{2}$.

2. Upper view of Atherfield specimen No. 2: *h.r.*, distal end of the right humerus; *r.r.*, proximal end of the right radius; *u.r.*, proximal end of the right ulna; *h.l.*, distal end of the left humerus; *W.mc.*, distal end of wing-metacarpals; *s.b.*, small bone, apparently articulating in semicircular emargination (*s.c.e.*) on the first wing-phalange, *1.W.ph.* B.M. R/3878. × $\frac{1}{4}$.
3. Left lateral view of the sternum: *cor.ar.fa.*, coracoid articular facets. B.M. R/3877. × $\frac{1}{2}$.
4. Slightly oblique anterior view of the sternum, to exhibit coracoid facets: *cor.ar.fa.* B.M. R/3877. × $\frac{1}{2}$.
5. Restoration of the dorsal outline of the sternum: *A*, anterior end. × $\frac{1}{2}$.
6. The right ischium: *ac.*, part of the acetabular rim. B.M. R/3877. × $\frac{1}{2}$.
7. The right femur, distal end partly destroyed: B.M. R/3877. × $\frac{1}{2}$.

Discussion.

The President (Dr. A. Strahan) desired to emphasize the importance of the work which had been carried out by the Author for some years past. Not only had a large number of valuable fossils been rescued from destruction by his care and perseverance, but by his skill in interpreting them conclusions of much interest had been placed before the Society.

Dr. C. W. Andrews congratulated the Author on his success in collecting such beautifully-preserved reptilian skeletons from the Wealden Beds of the Isle of Wight. He remarked that there was some doubt whether the generic name *Ornithodesmus* was applicable to the species now described, it having been applied originally to a number of fused vertebræ which differ materially from either of the two groups of fused vertebræ in the specimen now under consideration. The peculiarities in the arrangement of the temporal arcades and fossæ he considered to be entirely due to the nearly anteroposterior direction of the elongated quadrate. The Author's interesting account of the mechanics of the wing-bones, particularly of the carpal region, could not be profitably discussed in the absence of specimens and diagrams.

Dr. A. Smith Woodward expressed his admiration of the Author's work and perseverance. He hoped that, as soon as the paper was published, the specimens described would be mounted and exhibited in the British Museum (Natural History).

The Author briefly replied. He thanked the Fellows for the kind way in which they had received his paper. He said that the lengthening of the muzzle, as an aid in procuring food, had undoubtedly drawn forward the bones below the orbits. The facial portion of the skull was about $5\frac{1}{2}$ times that of the cranial. The length of the skull was 560 millimetres, and the spread of the wings when curved in flight about 5 metres.

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[No. 275 of the Quarterly Journal will be published next September.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

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Vol. LXIX. PART 3. OCTOBER 29TH, 1913. **No. 275.**

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

[With Ten Plates, illustrating Papers by Dr. H. Salfeld, Mr. H. Kay, Dr. A. Jowett, Mr. M. Odling, and Dr. C. A. Matley.]

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SESSION 1913–1914.

1913.		
Wednesday,	November	5*—19*
,,	December	3 —17*
1914.		
Wednesday,	January	7*—21*
,,	February (*Anniversary*, Friday, Feb. 20th)	4*—25*
,,	March	11 —25*
,,	April	8 —29*
,,	May	13 —27*
,,	June	10 —24*

[*Business will commence at Eight o'Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

19. *Certain* Upper Jurassic Strata *of* England. By Dr. Hans Salfeld, University of Göttingen. (Communicated by S. S. Buckman, F.G.S. Read June 11th, 1913.)

[Plates XLI & XLII.]

By combining the evidence of a number of sections in England and near Boulogne-sur-Mer I have succeeded in establishing a normal succession of zones in the Oxfordian, Kimmeridgian, and Portlandian rocks, using these terms according to the German and French classifications. Dispensing with A. d'Orbigny's separate stage of the Corallian, I agree with Oppel in extending the 'Oxfordian' stage up to the 'Kimmeridge,' the lowest zone of which, in accordance with the view of H. Douvillé, A. de Lapparent, and E. Haug, I recognize to be that characterized by *Pictonia baylei*, sp. nov. (=*Pictonia cymodoce* Bayle,[1] Tornquist, and others, non *Ammonites cymodoce* d'Orbigny). Further, I divide the Oxfordian into two portions: the lower chiefly yields *Cardiocerata* of the groups of *cordatum* and *tenuicostatum*, ending above with the zone of *Perisphinctes martelli* Oppel sp. and *P. biplex* de Loriol[2] (*Ammonites martelli* auctt., non *A. biplex* Sow.); the upper comprises the following zones in ascending order:—(1) Zone with *Perisphinctes wartæ* Bukowski, *Cardioceras (Amœboceras) alternans* von Buch sp. and allied species; (2) Zone with *Perisphinctes decipiens* J. Sow. sp., *P. achilles* d'Orb. sp., and *Cardioceras (Amœboceras) serratum* J. Sow. sp.; (3) Zone with *Ringsteadia* [gen. nov.][3] *pseudocordatus* Blake sp. (=*Ammonites mutabilis* Damon, *Proplanulites mutabilis* R. Douvillé, non *A. mutabilis* J. de C. Sow.) and other species of this new genus.

The Kimmeridgian in the German and French sense would comprise the following zones, taken in ascending order:—(1) Zone with *Pictonia baylei* sp. nov. and other species of *Pictonia*; (2) Zone with *Rasenia* [gen. nov.][4] *cymodoce* d'Orb. sp., *R. uralensis* d'Orb. sp., *R. thermarum* Oppel sp., in addition to others, and, further, *Cardiocerata* which have invariably been described as *Cardioceras alternans* von Buch sp., but belong to other species and other groups; for example, *C. kitchini* sp. nov. (=*Ammonites alternans* H. B. Woodward, 'Jur. Rocks of Britain' Mem. Geol. Surv. vol. v, 1895, fig. 68, p. 155); (3) Zone with *Rasenia mutabilis* J. de C. Sow. sp.

[1] E. Bayle, 'Explication de la Carte géologique de la France' vol. iv (1878) pl. lxvi; A. Tornquist, 'Die degenerierten Perisphinctiden des Kimmeridge von Le Havre' Abhandl. Schweiz. Paläont. Gesellsch. vol. xxiii (1896) pl. ii, pl. iii, figs. 1–2, & pl. iv, fig. 1. The genus *Pictonia* has hitherto been found exclusively in Northern France, England, and North Germany (Pomerania).

[2] P. de Loriol, 'Oxfordien supérieur & moyen du Jura Lédonien' Abhandl. Schweiz. Paläont. Gesellsch. vol. xxx (1903) pl. vi.

[3] See p. 427. [4] See p. 429.

(non *Ammonites mutabilis* auctt.); (4) Zone with *Aulacostephanus yo* d'Orb. sp. and *A. contejeani* Thurmann sp.; (5) Zone with *Aulacostephanus pseudomutabilis* de Loriol sp., *A. eudoxus* d'Orb. sp., *A. undoræ* Pavlov sp., *A. subundoræ* Pavlov sp., etc., and *Cardiocerata* which again have been described as *Cardioceras alternans* von Buch sp., but belong neither to this species (or group) nor to the group of *C. kitchini* sp. nov., but to a new group.[1] On the Continent we conclude the Kimmeridge or Kimmeridgian with this zone (5), following A. d'Orbigny's precedent; for no doubt can exist that the boundary with the Portlandian of that author falls above the beds containing *Ammonites eudoxus*, *A. pseudomutabilis*, etc., and below those yielding *A. gravesianus* d'Orb., etc.

The Portland or Portlandian in the German and French sense comprises the following zones, in upward sequence:—(1) Zone with *Gravesia* [gen. nov.][2] *gravesiana* d'Orb. sp. and other species; (2) Zone with *Gravesia irius* d'Orb. sp. and other species; (3) Zone with *Virgatites miatschkoviensis* Michalski sp. and other species; (4) Zone with *Perisphinctes pallasianus* d'Orb. sp. and other species; (5) Zone with *Perisphinctes pectinatus* Phillips sp.; (6) a zone marked by a new, densely-ribbed *Perisphinctes* (*P. eastlecottensis* sp. nov.)[3] from the Lydite Pebble-Bed at Swindon, which was apparently confounded with *P. pectinatus* by Blake; (7) Zone with *Perisphinctes gorei* sp. nov. (= *Ammonites biplex* de Loriol & Pellat[4] and *A. biplex* auctt. in part); (8) Zone with *Perisphinctes pseudogigas* Blake sp., a species which stands very near to *P. giganteus* J. Sow. sp. or *P. bononiensis* de Lor. sp., but is much more inflated; (9) Zone in which *Perisphinctes giganteus* J. Sow. sp. and *P. bononiensis* de Loriol sp. are found.

With this zone (9) the Portland or Portlandian in A. d'Orbigny's sense concludes. At a later time the formational designation 'Portlandian' was extended to include the Upper Volga Stage, the three *Craspedites* Zones, which, according to the work of Prof. A. Pavlov and others, must follow normally above Zone 9.

So much for the zonal subdivisions; let us now turn to the individual sections in England.

At the classic locality of Kimmeridge, which has given its name to the Kimmeridge Clay and to the formation 'Kimmeridgian,' the lowest subdivision seen in the flat anticline near the 'Lifeboat House' consists of clays with *Aulacostephanus eudoxus*, *A. pseudomutabilis*, etc., the fauna remaining unchanged up to the 'supposed Maple Ledge.' Above this bed up to the

[1] The monographic description of the genus *Cardioceras* will shortly appear in 'Palæontographica.'

[2] *Gravesia*, gen. nov.; genotype *Ammonites gravesianus* d'Orbigny, 'Paléont. franç.: Terr. jurass.' vol. i (1850) pl. ccxix.

[3] See p. 429.

[4] P. de Loriol & E. Pellat, 'Monographie paléont. & géol. des Étages supérieurs de la Formation Jurassique des Environs de Boulogne-sur-Mer' Mém. Soc. Phys. Hist. Nat. Genève, vol. xxiii (1874) pl. ii, fig. 1.

'Yellow Ledge'[1] the clays contain *Gravesiæ* flattened by pressure, those below belonging to the group of *Gr. gravesiana* d'Orb. sp., those above to the group of *Gr. irius* d'Orb. sp.

This is of great importance. It is not only that the *Gravesia* Beds are here recognized in England for the first time,[2] but we are thereby enabled to fix exactly the boundary between 'Kimmeridgian' and 'Portlandian' in the Kimmeridge section; that is to say, all that follows above the 'supposed Maple Ledge' must be correlated with the Portlandian.

The clays between the 'Yellow Ledge Stone-Band' and the 'Oil-Shales' form the equivalent of the *Virgatites* Beds, although I have never found a true *Virgatites* here. To the same zone we must also assign a part of the overlying clays. Somewhat below the 'White Septarian Band,' however, we reach the beds with *Perisphinctes pallasianus* d'Orb. sp. This zone must be recognized as extending up to the basal limit of the 'Portland Sands.'

Blake's statements concerning the ammonites contained in the Portland Sands and Portland Oolite of Purbeck, and also of Portland, I can, in the main, confirm. In the highest beds of the Portland Sand at Portland I found *Perisphinctes gorei* sp. nov., which indicates that the overlying Portland Oolite comprises the two zones characterized by *Perisphinctes pseudogigas* Blake sp. and *P. giganteus* J. Sow. sp. respectively, as assumed by Blake.

We may now consider the exposures in the neighbourhood of Weymouth. The Osmington Oolite yields *Perisphinctes martelli* Oppel sp., and accordingly corresponds with the uppermost zone of the Lower Oxfordian. The Sandsfoot Clay, from its position, must correspond to the zone of *Perisphinctes wartæ* and *Cardioceras alternans*. The Sandsfoot Grits yield *Perisphinctes achilles*, *P. decipiens*, *Cardioceras serratum*, and *Ringsteadiæ*, thus corresponding with the two upper zones of the Upper Oxfordian. Above the Sandsfoot Grits we may place the basal line of the Kimmeridge, lithologically not a very sharp division. The clays and marls which lie above the Sandsfoot Grits contain uncrushed *Pictoniæ*. Then follow thinly-laminated clays yielding *Rasenia cymodoce* and other species, above which are similar beds containing *R. mutabilis*, all much compressed. The beds with *Aulacostephanus pseudomutabilis*, *A. eudoxus*, etc., are exposed in the higher nodular layers. The zone of *Aulacostephanus yo*,

[1] For the position of these stone-bands, see A. Strahan, 'The Geology of the Isle of Purbeck & Weymouth' Mem. Geol. Surv. 1898, pl. x.

[2] The ammonites described by Prof. Pavlov & Mr. Lamplugh from the Speeton Clay as *Olcostephanus (Polyptychites) gravesiformis* are true *Polyptychites* of the Valanginian, and not identical (as assumed by the first-named writer) with species of the group of the *Gravesiæ* from the *Gigas*-Schichten of the lowest Portlandian of North-West Germany. See A. P. Pavlov & G. W. Lamplugh, 'Argiles de Speeton & leur Équivalents' Bull. Soc. Imp. Nat. Mosc. n. s. vol. v (1892) p. 482.

as also the *Gravesia* and *Virgatites* Beds of the Lower Portlandian, cannot be recognized here, because the section is, to a great extent, obscured by talus.

The clays below the Portland Sands here likewise yield *Perisphinctes pallasianus* throughout.

The section at Red Lane, Abbotsbury, described by Blake & Hudleston [1] (given by them in inverted order of succession) shows in Bed 2 of Blake a dark-brown, richly-ferruginous, soft oolite, containing in abundance *Waldheimia dorsetensis* Walk., *Rasenia thermarum* Oppel sp., *R. uralensis* d'Orb. sp., and other species. These 'Corallian Beds' of Blake are, therefore, the exact equivalents of the Lower Kimmeridge Clay of Weymouth, the zone of *Rasenia cymodoce*, a fact already recognized by Prof. H. Douvillé.

The exposures near Swindon prove that the Kimmeridge Clay facies, as shown in the clay-pit at Telford Road, extends down as far as the zone of *Perisphinctes decipiens* and *Cardioceras serratum*. Below this follow sandstones of the 'Corallian.' Clays with *Pictoniæ* are exposed at the base of Buzzard's Clay-pit in Swindon. The leathery shales at the top of the Lower Clay-pit contain *Aulacostephanus pseudomutabilis*, *A. eudoxus*, etc. Since the succeeding clays and marls yield *Virgatites*, the dividing-line between Kimmeridgian and Portlandian must here be placed immediately above the leathery shales. The *Gravesia* Beds are here either entirely wanting, or are condensed to a minimum.

It is known that *Perisphinctes pectinatus* occurs in the Portland Sands below the Swindon Clay. The Swindon Clay itself has yielded no ammonite. On the other hand, the 'Lydite Pebble-Bed,' immediately overlying the Swindon Clay, contains a new ammonite of contemporaneous age—a *Perisphinctes* related to *P. ulmensis* Oppel sp., *P. denseplicatus* Waagen, and *P. postulmensis* Blaschke—in addition to very numerous, rolled, phosphoritized and silicified fossils derived from lower horizons, particularly from the zone of *Perisphinctes pallasianus*. Immediately above, in the base of the calcareous sandstone, *Perisphinctes gorei* sp. nov. is abundant. The main mass of the calcareous sandstone yields *Perisphinctes pseudogigas* Blake sp. as the characteristic species. The overlying Swindon Sands may be regarded as equivalent to the zone of *Perisphinctes giganteus*, although it has not been possible to prove the occurrence of ammonites in them.

It is important to note that, in the Swindon neighbourhood, the sandy facies persists longer than at Portland and in Purbeck. The boundary which is there drawn between the Portland Sands and the Portland Oolite would fall at Swindon in the calcareous sandstone, above the zone yielding *Perisphinctes gorei*.

At Westbury the top of the Ironstone yields *Ringsteadiæ*; above

[1] J. F. Blake & W. H. Hudleston, 'On the Corallian Rocks of England' Q. J. G. S. vol. xxxiii (1877) p. 273.

this comes Kimmeridge Clay, which thus probably begins here with the zone containing *Pictoniæ*.

It can, therefore, be recognized that over the whole region described the change of facies between the Kimmeridge Clay and the Portland Sands occurs at one and the same time. The facies-division between Kimmeridge Clay and Corallian is, however, not chronologically constant, but changes to the extent of several zones even within short distances: thus, for instance, between Weymouth and Abbotsbury, or between Westbury and Swindon.

As regards other localities, I will merely emphasize the fact that the Kimmeridge Clay exposed at Market Rasen (Lincolnshire), which has furnished the splendidly-preserved ammonites that constitute a particular embellishment in many collections, has only yielded the fauna of the zone of *Rasenia cymodoce* and *R. uralensis*.

The foregoing account forms the first publication of a part of my comprehensive studies on the zonal subdivision and correlation of the Upper Jurassic formation (in the German sense) of Middle and North-Western Europe. The investigation of the faunas will be dealt with in separate monographs of the genera, to be published in 'Palæontographica.'

Finally, I wish here to express my warmest thanks to all those gentlemen who, by valuable advice and information and by giving access to collections, as well as by the loan of fossils, have supported and furthered my studies: particularly to Dr. A. Smith Woodward, Prof. W. J. Sollas, Mr. G. C. Crick, Dr. F. L. Kitchin,[1] Mr. S. S. Buckman,[1] Mr. Gore, and Mr. Barnes, in addition to others.

Appendix: Ammonite Names.

Ringsteadia, gen. nov.

Genotype, *Ammonites pseudocordatus* Blake, *emend.* Salfeld.

Blake's illustration, in Q. J. G. S. vol. xxxiii (1877) pl. xiii, fig. 1, scarcely reproduces the characters of the genus. Since the original specimen cannot be found, I take as type of the genus that ammonite from the same locality which agrees most closely with Blake's description. The following must rank as synonyms of *A. pseudocordatus* Blake, *emend.* Salfeld:—

1888. *Ammonites mutabilis* R. Damon, 'Supplement to the Geology of Weymouth & the Isle of Portland' pl. xvi, fig. 1.
1909. *Proplanulites mutabilis* R. Douvillé, Bull. Soc. Géol. France, ser. 4, vol. ix, pl. vii, fig. 1 & pl. viii, fig. 1.

The name is derived from Ringstead Bay, near Weymouth (Dorset).

[1] I am also indebted to Dr. Kitchin for translating this paper, and to Mr. Buckman for bringing together my results in the form of the table which follows (p. 428).

Tabular Summary of Results.

	Zones.	Strata.		
Portlandian.	9. *Perisphinctes giganteus* ...... 8. *Perisphinctes pseudogigas* ...	Portland. The Portland Oolite.		Swindon. Swindon Sands. Swindon. Calcareous sandstone.
	7. *Perisphinctes gorei*	Portland. Upper beds of Portland Sands.		Swindon. Base of calcareous sandstone.
	6. *Perisphinctes eastlecottensis*.			Swindon. Lydite Pebble-Bed.
	5. *Perisphinctes pectinatus*.....			Swindon. Sands above Swindon Clay.
	4. *Perisphinctes pallasianus* ...	Kimmeridge. White Septarian Band up to Sands.	Osmington. Clays below Portland Sands.	
	3. *Virgatites miatschkoviensis* .	Kimmeridge. Clays between Yellow Ledge and Oil-Shales.		Swindon. Clays and marls.
	2. *Gravesia irius* .... 1. *Gravesia gravesiana*	Kimmeridge. Clays below Yellow Ledge.		
Kimmeridgian.	5. *Aulacostephanus pseudomutabilis*........................	Kimmeridge. Clays below Maple Ledge.	Osmington. Higher nodular layers.	Swindon. Leathery Shales, Lower Clay-pit.
	4. *Aulacostephanus yo*			
	3. *Rasenia mutabilis*.............		Osmington. Laminated clays.	
	2. *Rasenia cymodoce*	Market Rasen. Clays.	Osmington. Laminated clays.	Abbotsbury. Iron ore.
	1. *Pictonia baylei*		Osmington. Clays and marls.	Swindon. Base of Buzzard's Clay-pit.
Upper Oxfordian.	3. *Ringsteadia pseudocordatus* .		Osmington.	Westbury. Top of iron-ore.
	2. *Perisphinctes decipiens*		Sandsfoot Grits.	Swindon. Telford Road Clay-pit.
	1. *Perisphinctes wartæ*		Osmington. Sandsfoot Clay.	
Lower Oxfordian.	*Perisphinctes martelli*.........		Osmington Oolite.	

RASENIA, gen. nov.

Genotype, *Ammonites cymodoce* d'Orbigny, 'Pal. Française : Terr. Jurass.' vol. i (1850) pl. ccii, figs. 1 & 2 (*non* figs. 3 & 4), & pl. cciii, fig. 1.

Another characteristic species is *Ammonites uralensis* d'Orbigny, in Murchison, de Verneuil, & Keyserling, 'Géologie de la Russie d'Europe' vol. ii (1845) pl. xxxii, figs. 6 & 7 (*non* figs. 8 & 9).

Rasenia comprises many of the so-called *Olcostephani* of the Kimmeridgian. The above-mentioned species belong to two distinct groups of *Raseniæ*, of which the first becomes smooth with age, while the second acquires strong, undivided ribs. *Rasenia* is a genus rich in species, which have their chief development in the Kimmeridge of Northern France, England, and the interior of Russia, but occur also as frequent accessory faunal constituents in Southern Germany, Switzerland, the middle and south of France, and the Alpine Jura.

The name is derived from Market Rasen (Lincolnshire).

PERISPHINCTES EASTLECOTTENSIS, sp. nov. (Pls. XLI & XLII.)

Ammonites pectinatus of English authors (in part).

Measurements.[1]

Diameter in millimetres.	*Breadth of whorl.* (Percentage of diam.)	*Thickness of whorl.* (Percentage of diam.)	*Width of umbilicus.* (Percentage of diam.)
170	37	36	37
145	36	37	37

Description.—This form possesses an oval whorl-section, even in youth; the greatest thickness is close to the umbilicus. The umbilical edge is rounded, the umbilical slope (inner margin) steep. The inner whorls overlap one another by about a half; in later whorls the overlap is rather less.

The ribbing is very fine and relatively weak, while the number of primary ribs is very great; at a diameter of 110 millimetres there are about 130 in a single whorl. At a diameter of 145 mm. the main ribs become gradually more widely spaced and stronger, while the number of external ribs, on the other hand, remains approximately the same. The ribs rise obliquely backwards from the umbilicus, and soon take a forward bend, running almost radially across the lateral area. The ribs divide in an irregularly fasciculate (virgatite) manner, and at all stages of growth pass over the periphery without any break. The first furcation of ribs occurs about the middle of the lateral area.

The inner whorls show, up to a diameter of about 85 mm., flattened, narrow constrictions almost parallel with the ribs.

The lobes and saddles are very finely divided. The deep external and first lateral lobes lie on the same radius; both are relatively broad. The second lateral lobe extends to somewhat more than

[1] For the method of giving proportions, see S. S. Buckman, 'Yorkshire Type Ammonites' pt. 9 (1913) p. viii.

half the length of the first; it is directed a little obliquely, and is likewise relatively broad. A 'suspensive' lobe, which extends down to a radius drawn from the external lobe, possesses three obliquely-directed auxiliary lobes. The saddles are more or less symmetrically divided by the primary indentations. The first lateral saddle extends somewhat beyond the external saddle.

The length of the body-chamber and the form of the aperture are not known.

Locality.—Swindon, above the so-called 'Swindon Clay,' at the base of the so-called 'Portland Oolite,' in the Lydite Pebble-Bed at Eastlecott railway-cutting.

Number of specimens studied.—Four.

Collections.—Geological Institute of the University of Göttingen; British Museum (Nat. Hist.), No. 88657.

Remarks.—*Perisphinctes eastlecottensis* stands near to *P. ulmensis* Oppel sp., from the *Gravesia* Beds (lowest Portlandian), to *P. denseplicatus* Waagen, and to *P. postulmensis* Blaschke. It is distinguished from these species, however, by its different proportions and its finer ribbing. In specimens having the same width of umbilicus, *P. eastlecottensis* possesses a considerably greater height and thickness of whorl.

P. ulmensis Oppel sp., at given dimensions, has a wider umbilicus, and possesses ribs which are stronger and broader and have a marked backward slope; in this species, also, the wider spacing of the primary ribs comes on at a much earlier age.

P. denseplicatus Waagen, from the Tithonian, and the very imperfectly-known *P. postulmensis* Blaschke, stand nearer to the English species than does *P. ulmensis* Oppel sp. *P. denseplicatus* has a wider umbilicus, and is considerably thinner and narrower in the whorl; also important differences in the lobe-line appear to be present, at least so far as the material that has been figured is concerned.

P. postulmensis appears likewise to have a wider umbilicus, and to show narrower and thinner whorls.

Virgatites quenstedti Rouillier is a form which has similar ribbing; but its whorl-section and proportions are quite different.

EXPLANATION OF PLATES XLI & XLII.

Plate XLI.

Portlandian, *eastlecottensis* zone.

Perisphinctes eastlecottensis, sp. nov. Holotype. Lydite Pebble-Bed, Eastlecott, Swindon (Wiltshire). Coll. British Museum (Nat. Hist.), No. 88657. Side view, ×0·7.

Plate XLII.

Portlandian, *eastlecottensis* zone.

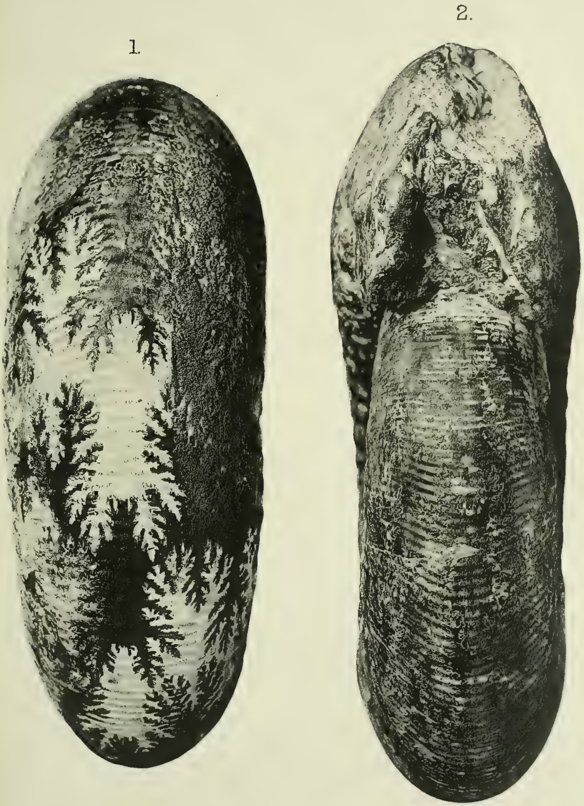
Perisphinctes eastlecottensis, sp. nov. Fig. 1, peripheral view; Fig. 2, apertural view of the example shown in Pl. XLI, both × 0·7.

J. W. Tutcher, Photo.

Bemrose, Collo., Derby.

PERISPHINCTES EASTLECOTTENSIS, sp. nov.

× 0·7



J. W. Tutcher, Photo.

Bemrose, Collo. Derby.

PERISPHINCTES EASTLECOTTENSIS, sp. nov.

×0·7

Discussion.

Dr. A. Morley Davies said that all who were working at the Upper Jurassic rocks would welcome this contribution to the difficult subject of their zonal correlation. His first comment on the zonal table exhibited was that it proved more clearly than before that the term 'Oxfordian' would have to be abolished. While several of the zones on the Author's list could at once be recognized, others had unfamiliar names, and among these he failed to identify such well-marked faunal horizons as those of *Amœboceras* (*alternans* zone) and *Physodoceras* (*orthocera* zone). The paper would, however, doubtless remove these difficulties, and explain why other index-fossils had been chosen.

Dr. F. L. Kitchin expressed satisfaction that he had given encouragement to the Author to lay before the Society the first fruits of his work in England. He considered that the paper made a great advance in our knowledge of the strata with which it deals: previous accounts of these rocks became thereby desirably supplemented by a detailed investigation, conducted from the purely zonal standpoint. The speaker regarded the Author as especially qualified to undertake this work, equipped as he was with sound palæontological knowledge and wide experience of typical Continental sections. He believed that the Author had conducted his field-observations with exemplary care, and that his results might, therefore, be accepted as substantially accurate, providing a sound basis for future work. It gave him pleasure to report that the Author hoped to return to this country next year, in order to continue these researches. Thanks were due to Mr. Buckman for bringing before the meeting this first valuable contribution.

Mr. G. W. Lamplugh said that the sequence of ammonite-zones demonstrated by the Author could not fail to prove of service to students of the British Upper Jurassic rocks. The succession and correlation seemed to be firmly based, and, so long as this was the case, the method adopted for grouping the zones into formations was of secondary consequence. The Author had followed the usual Continental grouping, which was not convenient for stratigraphical purposes in this country, where the use of Kimmeridge Clay as a descriptive lithological term could hardly be displaced.

The Author's discovery of the true horizon of the inflated *gravesianus* forms in the Kimmeridge section was of peculiar interest, because of the difficulties which had arisen through the original confusion of these forms with the *Polyptychites* of the Speeton Clay. The speaker desired to know by what features the species of this group are distinguishable when they are crushed flat. He mentioned that he had recently found specimens of *Aulacostephanus* in the Kimmeridge Clay of Filey Bay, at about the horizon indicated in the Author's scheme.

Mr. W. F. Gwinnell referred to the occurrence of ammonites in some of the Upper Jurassic zones under consideration, in the Northern Highlands of Scotland, on both the eastern and the

western shores. While in Inverness some seven years ago he obtained from Eathy Shore on the coast of Cromarty, in an indurated shale, a number of small specimens which were referred by Mr. G. C. Crick to the *Hoplites-eudoxus* group. All are small, some very small, and more or less crushed, but the shell is still pearly.

The PRESIDENT (Dr. A. STRAHAN) pointed out that this was a purely palæontological research on a region in which the strata were strongly differentiated by their lithological characters, and in which they formed conspicuous and characteristic features. In such a region the stratigraphical method of classification was forced upon the observer. But it was to be remembered that, while the stratigraphy was locally paramount, the palæontological method became essential in dealing with areas of a continental order of magnitude.

The part of Dorset with which the Author dealt was classic ground, inasmuch as it had given to the world such names as Purbeckian, Portlandian, Kimmeridgian. If Kimmeridgian meant anything, it should have meant the Kimmeridge Clay of Kimmeridge and the neighbourhood. Yet, on palæontological grounds, a not inconsiderable part of that formation had been transferred to the Portlandian, in order to harmonize with other parts of Europe.

Similar difficulties in reconciling the results of the stratigraphical and palæontological methods had arisen in the correlation of other formations, and would continue to arise so long as the stratigraphical and palæontological methods of nomenclature were confused. In the Table before him he saw a zonal classification founded solely on the palæontology, but into it had been introduced a nomenclature for the grouping of the zones which had been misappropriated from the stratigraphical column. The term Kimmeridgian was, in his opinion, a misuse in such an association. These remarks were not to be taken as an adverse criticism of the palæontological results which the Author had obtained. On the contrary, it appeared that a notable advance had been made in our knowledge of the sequence and correlation of the palæontological zones.

Mr. BUCKMAN, in reply, heartily thanked the Fellows on behalf of the Author for their kind reception of the paper: he would like to add his personal appreciation of its value. The President's suggestion that he (the speaker) should invent a dual nomenclature —one for the stratigraphical and another for the zoological sequence—appealed strongly to him, as he had done this in a paper published by the Society so long ago as 1898: that it was not carried on was due to intimation from 'the powers that be' that it was unnecessary. So he certainly commended the President's opinion. Various points raised in the discussion were dealt with in the paper itself, especially the questions of stratigraphy. The fault lay with the speaker and not with the Author, if the exposition had not dealt quite fully with these matters.

20. *On the* HALESOWEN SANDSTONE SERIES *of the* SOUTH STAFFORDSHIRE COALFIELD, *and the* PETRIFIED WOOD *found therein at the* WITLEY COLLIERY, HALESOWEN (WORCESTERSHIRE). By HENRY KAY, F.G.S. With an Appendix on *DADOXYLON KAYI*, sp. nov., by E. A. NEWELL ARBER, M.A., Sc.D., F.G.S. (Read April 23rd, 1913.)

[PLATES XLIII & XLIV.]

CONTENTS.

I. INTRODUCTION.

THE present paper deals with part of the higher beds of the Coal Measures, as developed in the South Staffordshire Coalfield. The generally accepted subdivision of the Upper Carboniferous rocks in this coalfield is:—

(4) Keele Series = Lower Permian.
(3) Halesowen Sandstone Series.
(2) Red Coal-Measure Clays or Old-Hill Marls.
(1) Productive Measures.

The object of the present communication is to describe in greater detail than has yet been attempted the Halesowen Sandstone Series, and more especially its relationship to the Keele Series above, and the Red Coal-Measure Clays below. Special attention to the Halesowen rocks has been stimulated by the fine natural exposures north of the Clent Hills, by the discovery of unrecorded exposures elsewhere (as shown in the sequel), and by the further discovery of the remarkable petrified wood found at Witley.

The paper is not an exhaustive account of the strata described, but merely an attempt to throw light upon a hitherto neglected subject.

I am indebted to Prof. Charles Lapworth for much encouragement in my work, and to Dr. Walcot Gibson for valuable suggestions. I am particularly indebted to Dr. E. A. Newell Arber for his scientific description of the petrified wood, and for the assistance that he has given in regard to the arrangement of the

paper. I would also return my thanks to Mr. W. H. Foxall, the Hon. Secretary of the Birmingham Natural History & Philosophical Society, for photographs and for assistance in the field; and to Mr. Jew, the Manager of Witley Colliery, for the facilities and personal help which he has afforded me. Several other persons have supplied me with useful information, and my thanks are due to them likewise.

II. Historical Notes.

Murchison[1] was the first to describe the strata of the Clent and Halesowen district in detail, and, although his classification is now obsolete, his description remains the classic account. He notes especially the conformable passage of the lower strata downwards into true Coal Measures, but includes all the rocks from the conglomerates of the Old-Hill Marls upwards in the 'Lower New Red Sandstone.'

Jukes[2] established the 'Red Coal-Measure Clays' and the Halesowen Sandstones as Upper Coal Measures, but was unable to complete in person his investigations in the Upper Red strata. The work which he left unfinished was completed by Ramsay[3] and Hull,[4] who classified the whole of the upper red rocks as Permian of the Salopian type.

Prof. Lapworth[5] noted the presence of a series of rocks superior to the Halesowen Sandstones, but inferior to the Permian. These he separated as a distinct group, which he termed 'The *Spirorbis*-Limestone Group' from the occurrence of a thin band of that limestone near Illey Mill.

Mr. W. Wickham King[6] has re-examined the red rocks of the district bed by bed, comparing them with the sequence found at Enville, and has separated them into Upper, Middle, and Lower Permian.

Mr. T. C. Cantrill[7] recorded the occurrence of *Spirorbis*-Limestone bands among the so-called 'Permian,' on the line of the Birmingham (Elan Valley) aqueduct; and Dr. Walcot Gibson[8] has claimed the whole of the so-called 'Permian' as Keele Beds of Upper Carboniferous age. There are signs, however, of an approaching compromise between these divergent views.

[1] 'The Silurian System' 1839, pp. 54–57 & 463–469.

[2] 'The South Staffordshire Coalfield' Mem. Geol. Surv. [Rec. School of Mines] 1st ed. (1853) pp. 165–66; 2nd ed. (1859) pp. 3–9, 28–31, 155, & 185.

[3] *Ibid.* p. 185.

[4] 'The Triassic & Permian Rocks of the Midland Counties of England' Mem. Geol. Surv. 1869, pp. 16–18.

[5] 'Sketch of the Geology of the Birmingham District' Proc. Geol. Assoc. vol. xv (1898) pp. 366–68.

[6] 'The Permian Conglomerates of the Lower Severn Basin' Q. J. G. S. vol. lv (1899) pp. 97–128.

[7] 'Summary of Progress of the Geological Survey for 1901' Mem. Geol. Surv. 1902, pp. 63–64.

[8] 'On the Character of the Upper Coal-Measures of North Staffordshire, Denbighshire, &c.' Q. J. G. S. vol. lvii (1901) pp. 261–62.

The different opinions arrived at by successive investigators appear to result from the order of their researches: those who describe the local descending sequence have carried boundaries downwards; while those who describe the ascending sequence have removed them upwards. The cause of this difference of opinion is stated by Murchison as follows:—

'The mere lithological character of many of these beds might still mislead the most practised geologist, if he had not worked out the relations of all the other rocks of the district.'[1]

He adds elsewhere (p. 56):—

'It appears, therefore, that between Hagley and Halesowen there are all the proofs of a Lower New Red Sandstone . . . . passing down into Carboniferous strata so gradually, that it is difficult to draw the line of separation, or define it with any accuracy upon a map.'

Dr. Walcot Gibson has, however, accomplished a work of great importance in correlating the sequence of Upper Carboniferous rocks in South Staffordshire with that of North Staffordshire, Denbighshire, and Nottinghamshire.[2] The importance of this step was foreseen by Jukes himself, and the work was apparently contemplated by him, though never carried into effect. In September 1847, in a letter to Ramsay,[3] he wrote:—

'I look upon the Bridgenorth and Bewdley coalfield, and that between Coventry and Tamworth, as the districts to enlighten us on the true relations between the Coal Measures of [*sic*] Y.R. (that is, Young Red, or Permian and Trias).'

He urges the need for

'the thorough working out of the midland districts, and comparison between north and south, tracing the marine and freshwater beds, etc.'

In February 1848, also writing to Ramsay, he says:—

'I hold . . . . the North Staffordshire coalfield to be the only one in Britain where the whole series of C.M. can be proved to exist. I'll draw out the case more at length in future.'

The correlation effected by Dr. Walcot Gibson is as follows:—

North Staffordshire.	South Staffordshire.	
(4) Keele Series.	Keele Series.	Red sandstones and marls.
(3) Newcastle-under-Lyme Series.	Halesowen Series.	Grey sandstones and shales.
(2) Etruria Marl Series.	'Red Coal-Measure Clays' =Old Hill Series.	Red marls and green grits.
(1) Blackband Series.	(? absent)	——

The Blackband Series is probably absent from the South Staffordshire Coalfield. The term 'Red Coal-Measure Clays' adopted by

[1] 'The Silurian System' 1839, pp. 55–56.
[2] Q. J. G. S. vol. lvii (1901) fig. 2, p. 263.
[3] 'Letters & Extracts, &c. of J. B. Jukes—Edited by his Sister' London, 1871, pp. 320, 321, & 346.

Jukes does not appear to be used locally, the beds being known as the Old-Hill Marls, or as the Oldbury Marls, from the districts where they are typically developed. For the Keele Series no local name seems to have been proposed.

The detailed work of Prof. Lapworth in the '*Spirorbis*-Limestone Group,' as also that of Mr. W. Wickham King in the Permian strata, is of the highest importance. Unfortunately, no such detailed work has been carried out in regard to the Halesowen Sandstones and the Old-Hill Marls, and the boundary between them has never been defined. The only further reference to these rocks that I have been able to trace, is contained in a brief abstract of a paper by Mr. King, 'On the Conglomerates of the Halesowen Sandstones,' read before the Birmingham Philosophical Society some twenty years ago.

III. The Red Coal-Measure Clays or Old-Hill Marls.

These beds are essentially argillaceous and of a dull-red or purple colour, with characteristic bands of green grit. The clays are rich in iron, often containing from 15 to 20 per cent. [1] They form the raw material of the celebrated 'Staffordshire blue bricks.' Some varieties, less ferruginous, are used in the production of terra-cotta for architectural work.

In the northern portion of the coalfield, a thin coal is found nearly midway between the base and the summit of the series.[2] At Ireland Green, near West Bromwich, this coal appears to be represented by some 18 inches of black bituminous shale, in which plant-remains are abundant and well preserved. At Old Hill, greenish-grey carbonaceous shales with coaly partings are found on or near the same level. Here also the plant-remains occur in great abundance.

The green grits are found both above and below this horizon, and often pass gradually into coarse ashy, greenish or brownish sandstones, which form the well-known 'Espley Rock' of the miner. In the southern portion of the coalfield, the upper 'Espley Rock' further develops into more or less massive conglomerates, particularly south and west of Old Hill. Some of the pebbles are

> 'large angular fragments of Lickey quartzite, the nearest outcrop of which is 6 miles south-south-east of Old Hill.' [3]

Others are of fossiliferous Llandovery sandstone, but very many

> 'consist of fragments of trap, not, however, of basalt or greenstone, but of brown and purple porphyry (or felstone) very like some of those so abundant in the Permian rocks of the Clent Hills.' [4]

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1 Wood & Ivery, 'Bricks & Brickmaking' Birmingham, 1878.

2 'Summary of Progress of the Geological Survey for 1910' Mem. Geol. Surv. 1911, p. 14.

3 W. Gibson, 'On the Character of the Upper Coal-Measures of North Staffordshire, Denbighshire, &c.' Q. J. G. S. vol. lvii (1901) p. 262.

4 J. B. Jukes, 'The S. Staffs. Coalfield' Mem. Geol. Surv. 2nd ed. (1859) p. 29.

Above these massive conglomerates other purple marls are found, and the highest beds of the series consist of alternations of coarse, ashy, pebbly sandstones with thin bands of purple marl (see pp. 438–39).

West of Homer Hill these alternations disappear, and the upper marls directly underlie the massive grey sandstones of the Halesowen Series, as may be seen in the cutting of the inclined tramway from Oldenhall Colliery to The Hayes, and also at the foot of Ham Dingle, near Pedmore. The clays worked in the large pit at The Hayes, on the eastern flank of the Netherton anticline, are associated with massive conglomerates, and lie lower in the series than the alternating beds above mentioned. I have had no opportunity of examining the exposures at Wollescote.

As in the case of the Etruria Marls of other Midland Coalfields, it has hitherto been deemed well-nigh hopeless to search for fossils in the Old-Hill Marls. I have, however, satisfaction in announcing my discovery of some four horizons at which plant-remains occur, and one of these contains also a scanty and diminutive fauna. The plants are now under examination by Dr. E. A. N. Arber.[1]

IV. The Halesowen Sandstone Series.

Distribution and Exposures.

The Halesowen Sandstones cover a strip of country 3 miles wide, ranging from the eastern boundary-fault of the coalfield at Quinton to the western boundary-fault near Pedmore, and lying between Cradley and St. Kenelms. South of this area small inliers appear on the flanks of the Lickey anticline at Rubery. Northwards small outliers are recorded by Murchison, near Kingswinford and Lower Gornal,[2] and by the officers of the Geological Survey at Daffodilly, near Great Barr.[3] Small exposures which I found at Cakemore, Rowley Regis Station, and the Blackheath brickworks, do not appear to have been recorded hitherto. The sandstones capping High Haden Hill, and referred by Jukes[4] to this series, are identified by me as belonging to the Old Hill Series.

In the Quinton district the surface is covered with Glacial drift, and exposures are few and insignificant. West of this, from Mucklow Hill to Pedmore, owing to post-Glacial denudation, magnificent exposures abound. Very noteworthy are the consecutive sections found in the valley of Illey Brook, and in the canal- and railway-cuttings, the roadsides, and the quarries around Halesowen. Still more noteworthy are the continuous sections displayed in the ravines cut by the streams flowing towards Cradley and Stourbridge. These descend the strike-face of the sandstone escarpment from summit to base.

[1] For preliminary report, see Geol. Mag. dec. 5, vol. x (1913) pp. 215–16.
[2] 'The Silurian System' 1839, p. 57.
[3] 'Sum. Progr. Geol. Surv. 1911' Mem. Geol. Surv. 1912, pp. 21–22.
[4] 'The S. Staffs. Coalfield' Mem. Geol. Surv. 2nd ed. (1859) p. 28.

General Observations.

The Halesowen Series is essentially arenaceous, although clays, coals, and impure limestones occur. As to colour, the prevailing tint is brownish grey, but beds are found which are green, blue, purple, red, brown, or yellow. Some beds present a mottled appearance, owing to the inclusion of fragments of other rocks. Others, again, are stained externally, and yield variegated sandstones on being worked. In texture, the lower half of the series shows a definite gradation from coarse conglomerate to fine-grained sandstone; while the upper half exhibits a twice-repeated change from fine sediment to coarse sandstone.

Calcareous matter is disseminated throughout the series, and lenticular beds of tough calcareous sandstone are common. Some of these are markedly ferruginous, and simulate fine-grained basalts in appearance. A peculiar calcareous conglomerate (the 'cornstone' of Murchison[1]) occurs frequently in irregular masses, but never in continuous beds.

The only animal remains yet found consist of *Spirorbis*, which occurs in thin, earthy, often nodular limestone associated with pale-blue clay at two horizons. Plant-remains are abundant, but are usually ill-preserved. They consist of Carboniferous species only. A definite sequence of beds is noted, as follows:—

(5) (a) Sandstones.
(5) (b) Pale-blue clay with *Spirorbis* Limestone, and impersistent coaly beds.
(4) Sandstones with much included material.
(3) Pale-blue clay with *Spirorbis* Limestone and a definite seam of coal.
(2) Sandstones.
(1) Passage-beds, mainly conglomeratic.

(1) The Passage-Beds.

Coarse, pebbly sandstones alternating rapidly with bands of purple marl have been shown (p. 437) to occur at the summit of the Old-Hill Series. These beds are well developed on Mucklow Hill between the clay-pit and the canal, and a typical exposure is seen in the canal-cutting. The purple bands are here reduced to mere partings, a few inches only in thickness, and the sandstone-layers are highly conglomeratic. A mass of tough calcareous conglomerate overlies the highest band of marl, but is merely an irregular pocket and not a persistent bed. Between the canal and the railway, pebbly sandstones with arenaceous partings occur, and ferruginous material is plentifully distributed. At the foot of the hill, the Illey Brook flows through a V-shaped ravine in grey sandstone, and forms a fine cascade, which falls into a large rock-basin excavated through the conglomerates into the alternating beds.

[1] 'The Silurian System' 1839, pp. 54–57.

No definite line of demarcation can be drawn between the beds with argillaceous partings and those which are wholly arenaceous. The pebbles throughout possess the same characters, and strongly recall the rocks exposed at the Lickey Hills, for they consist of Cambrian quartzites, Llandovery sandstones, and other rocks which are associated with these in that locality. The Llandovery sandstone-pebbles are often fossiliferous, and Mr. W. Wickham King has collected typical specimens from them.

There is a perfect gradation of the lower strata into the upper, and I propose, therefore, to group these together under the name of the Passage-Beds. Their total thickness, as seen on Mucklow Hill, is probably not less than 100 feet.

The Passage-Beds are well exposed on the summit and eastern face of Furnace Hill. They dip rapidly southwards, and disappear beneath brown and yellow sandstone in a cliff bordering the River Stour below Halesowen Church.

North of a line drawn from Furnace Hill westwards to Witley Lodge only purple marls are found, and south of this line only grey sandstones appear. The presence of a fault may, therefore, be inferred. The published Geological Survey maps indicate a small fault between Furnace Hill and Old Hawne Colliery, while a fault is exposed in the cutting along the mineral railway, immediately west of Witley Lodge. In this last exposure Espley Rock, covered by purple marls, abuts against massive grey sandstones.

Still farther west the fault may be inferred, since, at the spot where the road from Halesowen to Stourbridge crosses the Lutley Brook, a deep ravine, excavated in grey sandstone, occurs on the left hand, while Espley Rock and purple marls are seen on the right. In the ascent of the road towards Colman Hill, the marls are covered by conglomeratic Passage-Beds like those of Mucklow Hill; and these, in turn, pass under the grey sandstones, which occupy the higher ground.

Opposite Corngreaves Hall, the outcrop of the Passage-Beds is cut off by a small fault, but reappears at a lower level in the deep gorge of the River Stour. From this point the outcrop runs westwards through Cradley, where the Passage-Beds form the steep ridge upon which the church is built. On the northern face of Homer Hill the beds are again exposed, though much reduced in thickness, the pebbles being also of smaller size. On the western side of the hill the beds disappear entirely. In the inclined tramway-cutting at Oldenhall Colliery, grey sandstones rest directly upon somewhat sandy purple marls; and at Ham Dingle, on the margin of the coalfield, the junction of the two series is of the same character.

Wherever they occur, the Passage-Beds constitute a perfect gradation from the Old-Hill Series into the Halesowen Series, thus proving that the relation between the two series is one of perfect conformity. The thinning-out and disappearance of the Passage-Beds westwards, however, is a feature of considerable importance, which should be correlated with other facts recorded on pp. 449–51.

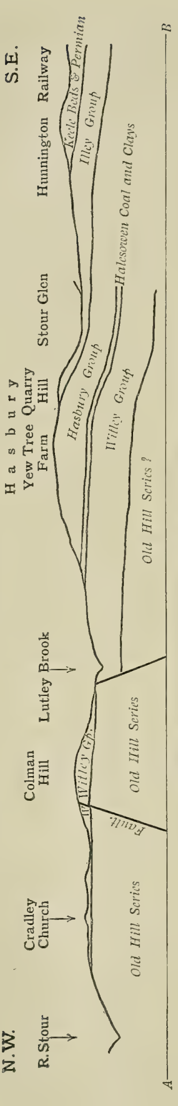


Fig. 1.—*Section through Cradley and Hasbury to Hunnington (AB on the map, Pl. XLIV).*

[Scales: Horizontal, 2 inches = 1 mile; vertical, 1 inch = 750 feet.]

(2) The Witley Group.

The finest section of the grey sandstones which overlie the Old-Hill Series is found in the cutting of the inclined tramway at Oldenhall Colliery. The purple marls extend upwards to a small bridge crossing the tramway near the 500-foot contour-line, and are covered by coarse, brownish-grey sandstone containing a few small and scattered pebbles of quartzite. No break occurs in the sandstones, but the highest beds here seen are finer in texture and lighter in colour than those lower down. In the colliery-shaft, at the head of the incline, 45 yards of sandstone rock were proved.[1]

Similar sandstones extend over the area eastwards to Colman Hill and northwards to Homer Hill and Cradley. They exhibit the same upward gradation in texture and colour. In the Colman-Hill district they contain lenticular beds of dark calcareous sandstone, and 'ironstone' is reported from a well-sinking in the same locality.[2] The dip of the strata at Oldenhall is 15° east-south-eastwards.[3]

These beds are only a portion of a thicker group, inasmuch as higher sandstones, dipping at 25° westwards,[3] are met with on the western side of the Hayes Fault at Careless Green. Calcareous sandstone also occurs here, but the general character of these upper beds is that they are fine in texture, greenish in colour, and slightly micaceous. The colour changes into a pale yellow towards Lushbridge, where clays containing a 1-foot coal are found at a higher level.[4]

[1] From information supplied by Mr. Bangham, Oldenhall Colliery.

[2] From information supplied by Mr. Jew, Manager of Witley Colliery.

[3] Geological Survey 1-inch map, Sheet LXII, S.W.

[4] From information supplied by Mr. Bangham.

In the ravine below Lutley Mill, sandstones are seen which strongly resemble those around the shaft of Oldenhall Colliery. In the Lutley Gutter, these pass under fine yellowish sandstone, which in turn underlies blue clay containing a thin coal-seam. In the cutting of the mineral railway below Witley Lodge, the lowest sandstones exposed also resemble those found at Oldenhall, and they occur some 70 feet below clays containing a 2-foot seam of coal. The entire thickness of the group may, therefore, be estimated at not less than 200 feet.[1]

In the Witley exposure the beds are seen to great advantage. Quartzite pebbles 1 or 2 inches in diameter are occasionally found. Pockets of 'cornstone' occur, with lenticular beds of calcareous sandstone. Numerous rounded concretions of dark, ferruginous, yet highly calcareous sandstone are also found, and these weather with rusty exfoliating coats. Plant-remains are abundant, and are occasionally well preserved. The most interesting feature of the exposure, however, is the occurrence of big logs of petrified wood, resting upon, surrounded by, and overlain by undisturbed sandstone. Fossil wood of a similar type of preservation was met with in the shaft of Oldenhall Colliery.[2]

These higher beds of the group are found around Wollescote Hall, at Careless Green, in the central portion of the Lutley Valley, and in the districts lying north and east of Halesowen. They occur also below the summit of Mucklow Hill, and are exposed in the brickworks at Blackheath, at Rowley Regis Station, and at Cakemore.

Fig. 2.—*Section from Yew-Tree Farm to Mucklow Hill (CD on the map, Pl. XLIV).*

[Scales: Horizontal, 2 inches=1 mile; vertical, 1 inch=750 feet.]

So far as I am aware, these beds are distinguishable from all other sediments of the Halesowen Series by the combined characters of fine texture, greenish or yellow colour, and the presence of mica. Texture alone is not peculiar, similar colours are seen in other beds, but the presence of mica does appear to be characteristic, and the combination of these characters is distinctive. The importance of this generalization may be seen in the fact that this combination of lithological characters is exhibited by sandstones occurring

[1] In Ham Dingle there is present only some 70 or 80 feet of sandstone above the purple marls, the lower beds of the Witley Group being entirely absent.

[2] From information supplied by Mr. Baugham.

at Rubery, in the stream-course south of the station. From this I infer that these sandstones belong to the highest members of the Witley Group, and in consequence I assign the clays and 2-foot coal which occur on the flanks of the Lickey anticline to the horizon of the Halesowen Coal and Clays, and not to the Illey Group as surmised by Prof. Lapworth.[1]

(3) The Halesowen Coal and Clays.

Murchison[2] repeatedly mentions 'coal at Halesowen,' but so vaguely that its position cannot be recognized. Jukes[3] makes no reference to it, although he cites Ham Dingle, the Lutley stream-courses, Uffmoor Wood, and The Leasowes as localities where 'a thin coal or coals' may be found. Outcrops of coal are marked at these places on the published maps.[4] Other 'coaly traces' are known to occur in Wassel Grove Dingle,[5] in the Hasbury quarries,[6] in the '*Spirorbis*-Limestone Group' at some point not specified,[7] and at Rubery.[8] It is, therefore, important to ascertain whether these occur at one or more horizons, and in the latter event to distinguish between them.

In Ham Dingle the coal is 1 foot thick, and forms a distinct ledge in the stream-course half way up the ravine. It is associated with yellow (blue where unweathered) clays above and below, and the total thickness does not exceed 10 feet. Traces of coal in a similar position are found in Hodge-Hill Dingle, and an exposure of coal by the side of a pool in Lushbridge Hollow was pointed out to me by Mr. Bangham. Here the outcrop is cut off by the Hayes Fault, and neither coal nor clay appears north or east of Oldenhall.

At Fatherless Barn a fault is to be inferred, since sandstones dipping east-south-eastwards at 15° occur on the north, and horizontal sandstones separated by clays on the south. The clay outcrop can be followed into the ravine known as the Lutley Gutter, where coal is exposed. Clay also occurs in the fields below Lutley Grange, and the outcrop runs up the Lutley Valley, where coaly beds appear at a point 704 yards from Wassel Grove, as mentioned by Jukes.[9]

In the course of a stream descending from Bog's Farm, some 30 feet of pale-blue clay containing nodules of earthy limestone is seen. Coal, however, is not exposed. A persistent outcrop of clay runs from this point to the Stourbridge road near Witley Lodge, and this was examined by me, accompanied by Mr. Jew,

[1] 'Sketch of the Geology of the Birmingham District' Proc. Geol. Assoc. vol. xv (1898) p. 368.
[2] 'The Silurian System' 1839, pp. 54–57.
[3] 'The S. Staffs. Coalfield' Mem. Geol. Surv. 2nd ed. (1859) pp. 28, 29.
[4] 1-inch Geological Survey map, Sheet LXII, S.W.
[5] 'Silurian System' *loc. cit.* [6] *Ibid.*
[7] Proc. Geol. Assoc. vol. xv (1898) pp. 366, 368.
[8] W. D. Conybeare & W. Phillips, 'Geol. of England & Wales' 1822, p. 417.
[9] 'The S. Staffs. Coalfield' Mem. Geol. Surv. [Rec. School of Mines] 1st ed. (1853) p. 166.

Manager of Witley Colliery, and a miner from that pit. The miner pointed out a spot where he had seen the coal proved. It was here 2 feet thick, 'with light-blue clay above and stiff blue clay below.' Other places where the coal had been exposed were also indicated. *Spirorbis* Limestone occurs in this clay near the colliery.

From Witley Lodge the outcrop appears to run on the south side of the road into Halesowen. No exposure is now seen, but a Halesowen resident kindly pointed out to me a grass-grown excavation above Queen Street, as the site of a former brickworks where the clay was burnt with coal from a 3-foot seam found in the clay-pit.

There is also reason to believe that coal underlies the town of Halesowen from this point eastwards to the churchyard, since it has been proved in sewerage excavations in the streets of this locality. The churchyard is certainly situated on yellow (or blue) clays, in which indications of the presence of coal are found.

South of the churchyard is a broad hollow which appears to have been once excavated somewhat extensively, but now shows only a clayey surface. This may well have been the site of the 'coalworks' mentioned by Murchison.

At this point the beds bend somewhat sharply south-eastwards, as the next exposure is in the bed of the River Stour, and clays are seen in an adjoining lane to pass under pale-brown sandstones dipping south-eastwards. This is the lowest point of the outcrop.

A thin covering of clay occurs at 'The Mount,' and clay dips into the steep ascent of the Bromsgrove road below 'The Grange.' On the eastern side of Illey Brook, clay is found along the railway, and in the banks of the canal, where coaly traces have also been seen. The beds are here rising at about 40° towards the Russell's-Hall Fault, by which they appear to be cut off, as they occur in a different position in the ground beyond.

East of The Leasowes, clays are well developed near the 600-foot contour-line, and beds above that level show fragments of coal in every rabbit-burrow and mole-heap. An outcrop of coal was mapped at this point by Jukes. Still farther east blue clays are exposed in Spies Lane, and shallow coal-mines were formerly worked at Moor Street. North of Mucklow Hill, pale-blue clays were formerly made into drain-pipes and tiles at the Bellevue Potteries, and it may, therefore, be inferred that the beds underlie the Glacial drift which occurs upon the higher ground. A fault is visible immediately north of the last-named exposure, and no further indication of the presence of the beds is found between this point and the brickworks at Blackheath, where a 1-foot coal is seen, associated with bluish clay from which Dr. Walcot Gibson obtained *Spirorbis* Limestone exhibiting the characteristic fossil.

It is, then, possible to trace pale-blue clays, which are associated with a variable but persistent seam of coal and with earthy *Spirorbis* Limestone, from the western boundary-fault to the eastern borders of the district. A definite horizon is thus established in

the Halesowen sequence, which is of great importance in regard to the classification of the Series. Other pale-blue clays, which are accompanied by 'coaly traces' or impersistent thin coals and by *Spirorbis* Limestone, also occur, but these can readily be proved to lie at a higher horizon.

The name of the Halesowen Coal and Clays may be applied to these beds, the thickness of which varies from 10 to 50 feet, being greatest within the town of Halesowen.

(4) The Hasbury Group.

Above the Halesowen Coal and Clays occurs a group of sandstones which present special features of their own, owing to the presence of fragmentary foreign material. In the Lutley Valley, in a lane near the River Stour, and in Manor Lane, soft brown sandstones are seen, in which transported peaty material occurs. Above these are paler sandstones, speckled with indurated red marl and with coal-dust. Higher beds contain small pellets of the same materials, together with flakes of a peculiar white ash and tiny quartzite-pebbles. In the old quarries near Yew-Tree Farm on Hasbury Hill, the blocks contain so much of the marl that they assume a dull purple hue, speckled with white, black, and yellow; and sandstones similar to these occur in the lanes and stream-course near Illey Mill.

A like succession of beds is found above the 1-foot coal in Ham Dingle, but in Hodge-Hill Dingle and Wassel-Grove Dingle the higher and redder beds are not exposed. Beds similar to those of the two last-named localities are seen near the entrance to the Lappal Tunnel.

Along a line from Ham Dingle to Lushbridge and thence to the northern parts of Hasbury Hill, the beds appear to be horizontal; but south of a second line from Bog's Farm through the southern portion of Hasbury Hill and the southern parts of the town of Halesowen, the beds dip from 15° to 20° south-south-eastwards, and disappear beneath a group of rocks which has still to be described. From their characteristic development near Hasbury, these beds are named the Hasbury Group. Their thickness varies from 120 to 150 feet.

(5) The Illey Group.

The remaining portion of the Halesowen Series forms the group separated by Prof. Lapworth under the title of the '*Spirorbis*-Limestone Group.' In consequence, however, of the discovery of that limestone at other horizons (p. 443), the group is now re-named the Illey Group, from the locality whence it was first described.

The description given by Prof. Lapworth is as follows:—

'A thin series of red, grey, and olive-coloured shales and sandstones with a band of *Spirorbis* limestone and a few thin coaly beds.'[1]

[1] 'Sketch of the Geology of the Birmingham District' Proc. Geol. Assoc. vol. xv (1898) p. 366.

The red beds seen near Illey Mill have already been assigned to the Hasbury Group (p. 444). Grey and olive-coloured shales and sandstones follow these in ascending sequence in the Illey stream-courses. The 'coaly beds' have not been located by me, unless these be identical with thin Coal-Measure binds recently exposed in a roadside-cutting at Lower Illey. In this exposure a sharp but low anticlinal fold is seen, and the binds are overlain by massive, coarse, brown grits. Similar grits are found at Cooper's Wood, farther east, where they overlie thin shaly sandstones from which I obtained an impression of *? Pecopteris*. In Kettle's Wood the grits pass beneath bright-red marls belonging to the Keele Series.

The true base of the Illey Group would appear to be certain grey, yellow, or blue clays and shales containing earthy *Spirorbis* Limestone, and seen immediately above Illey Mill. Clay-land extends from this point north-eastwards to near the Lappal Tunnel, and north-westwards towards The Grange.

In the Stour Glen, west of the last-named point, and reaching as far west as Uffmoor Wood, pale-blue or yellow clay is strongly in evidence. In Uffmoor Wood a thin coal appears in the bed of a stream, but this has not been found elsewhere. Still farther west the whole group disappears beneath the bright-red clays of the Keele Series.

I have not traced the upper boundary of the group between the Gypsy's Tent and Lower Illey, the line laid down by Jukes, Ramsay, and Hull having been accepted for the present.

There remains to be noticed the remarkable exposure of bright-red sandstones found on Quarry Hill, south of Hasbury, and formerly mapped as Permian strata. These beds yield good building-stone, and have been extensively quarried. They are red in external appearance only, since the blocks obtained from them are either red, variegated, or creamy brown. Bright-red marl is found in the rock-crevices, together with crystalline calcite. The rock-partings are formed of dull-red marl mingled with coal-dust and white ash, or wholly of transported coaly material, in which case they appear as coal-seams a few inches thick. Rounded lumps of coal, of lignite, of red and yellow ochreous material likewise occur, together with rolled pith-casts of *Calamites* and other Coal-Measure fossils.

At the base of the new quarry a lenticular bed of dark, tough, calcareous sandstone occurs. Quite recently a slab of this rock was raised, to the under side of which pale-blue clay was found adhering, and I was informed that clay of this kind underlies the whole quarry. It was stated that on the northern side it was but an inch or two thick, though it was 15 inches thick in the south-eastern corner. The beds dip at 15° to 20° south-south-eastwards. The slope of the hill, however, is greater still, with the result that the clay reappears in the valley below, where it is widely exposed, as already shown.

It is, therefore, clear that the beds seen in these quarries are

SYNOPTIC VIEW OF THE HALESOWEN SUCCESSION.

Series.	*Group.*	*Description.*	*Localities.*
The Keele Series.		Bright-red marls, red and mottled sandstones with calcareous cornstones, plant-remains, and three (?) bands of *Spirorbis* Limestone.	Frankley. Upper parts of Illey stream-courses, Stour Glen. Hagley Wood.
The Halesowen Sandstone Series.	The Illey Group. 80 to 100 feet.	Red-stained, grey, olive, brown, and yellow sandstones and shales with coaly traces, and a band of *Spirorbis* Limestone. Texture: fine to coarse. (= Prof. Lapworth's *Spirorbis*-Limestone Group.)	Cooper's Wood. Illey. Lower Illey, Illey Mill, and Stour Glen. Quarry Hill.
	The Hasbury Group. 100 to 150 feet.	Red, brown, mottled, green or grey sandstones with much 'foreign' matter (coal, lignite, indurated red marl, red and yellow ochre, flakes of white ash, small quartzite-pebbles). Calcareous sandstone, cornstone, traces of coal. Texture: fine to coarse.	Lappal Tunnel. Bromsgrove-road hill, Hasbury. Bog's Farm. Wassel Grove. Hodge Hill. Ham Dingle. Upper parts of Lutley streams and Hodge-Hill Dingle. Manor Lane. Illey Mill.
	The Halesowen Coal-Beds. 10 to 50 feet.	Variable but persistent coal-seam, with stiff blue clays above and below. *Spirorbis* Limestone.	Ham Dingle. Lushbridge. Lutley Valley. Halesowen, Mucklow Hill, Quinton, Blackheath. Rubery.
	The Witley Group. 200 feet.	Grey, brownish, or yellow sandstone. Calcareous sandstone in lenticles or concretionary masses. Ferruginous ball-stones. Cornstones. Quartzite-pebbles. Plant-remains. Fossil wood. Texture: coarse to fine.	Ham Dingle. Oldenhall. Cradley. Colman Hill. Witley. Northern and eastern parts of Halesowen. Mucklow Hill. Blackheath. Cakemore. Rubery.
	The Passage-Beds. 0 to 100 feet.	Arenaceous conglomerates or pebbly sandstones, with thin purple marl-bands in the lower part. Much ferruginous matter. Cornstones.	Mucklow Hill. Furnace Hill. Colman Hill. Cradley. Homer Hill.
The Old-Hill Marl Series.		Dull-red or purple marls with green grits and ashy conglomerates, or Espley Rock.	All the country north of the sandstone area.

superior to, and conformable with, the argillaceous beds which form the base of the Illey Group. They appear, however, to have been accumulated under local conditions similar to those which prevailed more generally during the formation of the Hasbury Group: namely, the occasional distribution in the sediment of material derived from the denudation of red Coal-Measure clays and of coals. The bright-red coloration is evidently a subsequent feature, due to staining from above.

V. The Disposition of the Beds.

(1) Folding.

At the southern end of the South Staffordshire Coalfield a deep syncline appears, ranging about south-south-eastwards through Halesowen and Illey, while there is a tendency to anticlinal conditions observable in the neighbourhood of the eastern and western boundary-faults. The synclinal structure is indicated by the following observations:—

From Furnace Hill to Lower Illey the rocks dip persistently south-eastwards, and the Thick Coal at Witley dips towards Halesowen at 1 in 13.[1] From Coombeswood to Cooper's Wood a high south-westward dip prevails, which is as much as 35° on Mucklow Hill, while the Thick Coal dips westwards at 1 in 6.[2]

The tendency to anticlinal conditions between the line last indicated and the eastern boundary-fault was noted by Jukes.[3] It is also apparent from the low east-south-eastward dip of the strata at the Bellevue Potteries and thence southwards to Moor Street. The beds of the Halesowen Coal and Clays, exposed in the Leasowes Estate at over 600 feet O.D., are reached only in shallow mines on the lower ground at Moor Street.

The western anticline does not appear to have been recorded hitherto, but is apparent from the fact that, whereas the highest members of the Hasbury Group are found near the 500-foot contour-line at Ham Dingle and at Hasbury, lower members of the same group appear 100 feet higher on Hodge Hill. The elevation, however, is slight in comparison with the breadth, and the western limb of the anticline is cut off by the boundary-fault of the coalfield.

An important flexure traverses the district from near Wassel Grove to Hasbury and the southern parts of Halesowen (p. 444). This feature does not appear to have been adequately recognized by previous observers, and its neglect has resulted, in one instance at least, in the fruitless endeavour to reach the Halesowen Coal-seam by shallow mining in the Stour Glen near St. Margaret's Hill. Jukes appears to have regarded the 'little coals' of Uffmoor Wood

[1] W. Mathews, 'The Halesowen District of the South Staffordshire Coalfield' Proc. Birm. Phil. Soc. vol. v (1887) p. 322.
[2] *Id. ibid.*
[3] 'The S. Staffs. Coalfield' Mem. Geol. Surv. 2nd ed. (1859) pp. 151–52.

and the 'good Coal-Measure beds' of the brook farther east as identical with the similar beds found in the Lutley Valley, and as 'cut off . . . . by a fault which is an upcast to the south.'[1] As already shown (pp. 445–47), the beds in question belong to the Illey Group, and are separated from those of the Lutley Valley by the full thickness of the Hasbury Group. It is worthy of note that the Illey Group is confined to the area south of the line of flexure indicated.

(2) Faulting.

The Halesowen Sandstones range up to the boundary-faults of the coalfield, and may therefore be presumed to underlie the strata for some distance farther east and west. These faults are described by Jukes in detail.[2] The remaining faults which affect the area occupied by the Halesowen Series are:—

(*a*) The Russell's-Hall Fault.—This also is fully described by Jukes, who says that

'at Coombs Wood . . . . it seemed as if the fault were there passing into a sharp anticlinal curve.' (*Op. cit.* p. 151.)

He notes that on Mucklow Hill it is rather a rude anticline than a clean-cut fracture or fault, since Coal-Measure sandstones are seen which dip 3° eastwards on one side of it and 30° or 40° south-westwards on the other. These sandstones, however, may be identified as members of the Witley Group, and of the upper 'Espley' Rock of the Old-Hill Series respectively, since the former consist of grey sandstones underlying the blue clays of the Bellevue Potteries, and the latter underlie the purple marls seen in the clay-pit farther down the hill. Consequently, it would appear that there is still a very considerable fracture.

(*b*) The Hayes Fault.—This is described by Jukes as

'a fault [running] parallel to the Netherton anticlinal on the eastern side of it from Careless Green' northwards. (*Op. cit.* p. 155.)

The fault appears to intersect the anticline obliquely near The Hayes, and this has led to the curious southward termination of the anticline which is shown on the published maps.

(*c*) The Cradley-Park Fault.—A fault is visible in the inclined tramway-cutting at Oldenhall, and the dislocation extends east-north-eastwards through Cradley Park, where the Thick Coal is thrown down northwards for 15 yards.[3] Still farther in the same direction is the fault crossing Colman Hill to Corngreaves Hall (p. 439). The sandstones of the Witley Group are thrown down

[1] 'The S. Staffs. Coalfield' Mem. Geol. Surv. 2nd ed. (1859) p. 155.
[2] *Ibid.* pp. 175–83.
[3] From information supplied by Mr. Bangham.

northwards in the Cradley area and the direction of their dip is modified. The continuity of the fault is, therefore, apparent.

(*d*) The Oldenhall Fault.—This appears on the published maps as a very short line branching east-north-eastwards from the Hayes Fault, a little south of the Oldenhall Colliery. South of the dislocation thus indicated, horizontal beds of sandstone occur, which, in the Lutley Gutter, are seen to overlie the Halesowen Coal and Clays: they are, therefore, members of the Hasbury Group. North of the fault the sandstone beds belong to the Witley Group, since in the colliery-shaft and in the tramway-cutting they overlie the purple marls of the Old-Hill Series.

Evidence of faults along the same line eastwards has already been given (p. 439). The exposures are practically continuous, and therefore a single line of fracture is indicated on the accompanying map (Pl. XLIV). The beds are thrown down southwards along the whole line, but evidence as to the amount of throw is not available. The fault appears to hade southwards, and to intersect the shaft of the Witley Colliery, but information as to its position in the workings is not forthcoming. Still farther east a fault is exposed in the banks of the Canal, and also near the Bellevue Potteries. Each of these exposures is likewise in the line of the Oldenhall and Furnace-Hill dislocation, and may possibly be connected therewith.

(*e*) The fault running through Hasbury and Hayley Green, which is shown on the published maps and was inferred by Jukes,[1] is omitted, inasmuch as no evidence for it has been met with on the ground, and the features indicated by Jukes are sufficiently explained by the occurrence of two similar series of beds separated by highly inclined strata, as shown on p. 444. A second fault, shown on the same maps from Hunnington to Old Hill, is an obvious error, being in reality the line of a horizontal section (No. 10: Sheet 25).

VI. Unconformities.[2]

The first unconformity occurs at the base of the Witley Group, and is confined to the area west of Cradley and the Lutley Valley. The evidence for it is as follows:—

Oldenhall Colliery stands at 580 feet O.D., and its shaft passes through 135 feet of sandstone (Witley Group), some marls and conglomerates (Old-Hill Series), and the productive Coal Measures. The Thick Coal is reached at a depth of 484 feet, or 96 feet above sea-level. It lies horizontal from north to south, but has a slight eastward dip.

[1] 'The S. Staffs. Coalfield' Mem. Geol. Surv. 2nd ed. (1859) p. 155.

[2] This information is gleaned partly from observation, partly from Jukes's Memoir, partly from Mr. W. Mathews's paper on 'The Halesowen District of the South Staffordshire Coalfield,' and partly from conversations with the managers at the mines.

The Wassel-Grove sinking is a mile and a quarter south of Oldenhall, and stands also at 580 feet O.D. The shaft commences near the summit of the Hasbury Group, and the beds pierced are :—

Sandstone, 123 feet (Hasbury Group).
Blue binds, 4 feet (Halesowen Coal and Clays).
Sand-rock, 38 feet (Witley Group).
Productive Coal Measures.

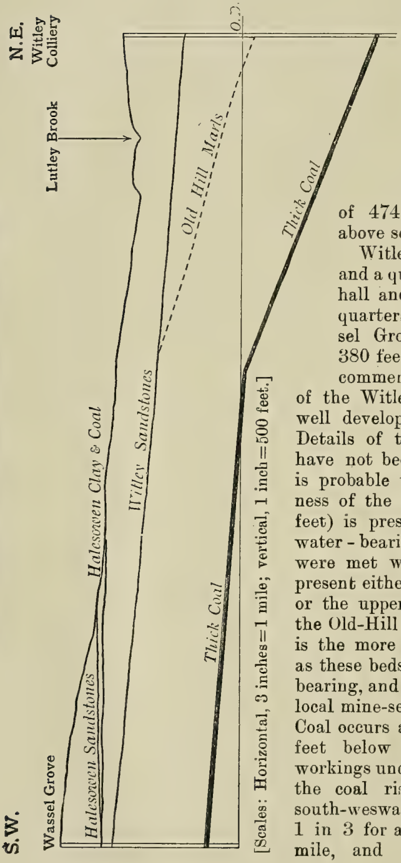


Fig. 3.—*Section from Wassel Grove to Witley Colliery.*

[Scales: Horizontal, 3 inches = 1 mile; vertical, 1 inch = 500 feet.]

The Old-Hill Marls are not represented. Thick Coal is not present in workable form, but certain 'seven-yard measures' are thought to represent it. These occur at a depth of 474 feet, or 106 feet above sea-level.

Witley Colliery is a mile and a quarter east of Oldenhall and a mile and three-quarters north-east of Wassel Grove. It stands at 380 feet O.D., and the shaft commences near the summit of the Witley Group, which is well developed in the vicinity. Details of the upper measures have not been preserved, but it is probable that the full thickness of the Witley Group (200 feet) is present. At 267 feet water-bearing conglomerates were met with; these may represent either the Passage-Beds, or the upper 'Espley Rock' of the Old-Hill Series. The latter is the more probable, inasmuch as these beds are usually water-bearing, and are found in all the local mine-sections. The Thick Coal occurs at 831 feet, or 451 feet below sea-level. The workings underground show that the coal rises westwards and south-weswards at 1 in 6 and 1 in 3 for a distance of half a mile, and afterwards flattens

very considerably. The average rising gradient towards Fatherless Barn is 1 in $5\frac{1}{2}$.

The last-named locality is half a mile west of Witley, and the coal here is only 17 feet below sea-level, while at the Beeches Colliery, half a mile farther west, it is 65 feet above that datum. The district in question is traversed by the Oldenhall Fault, with a southward downthrow, and this probably intersects the shaft of the Witley Colliery, as stated on p. 449. The amount of throw, and of the consequent interruption in the workings, has not been ascertained.

Thus, west of Witley, the productive measures are found to rise sharply westwards, the amount of rise being 434 feet in half a mile. In the next half-mile they rise but 82 feet, and in a quarter of a mile farther west, 31 feet only. We may, therefore, consider that these measures are folded into an anticlinal form, the axis of which ranges north and south, but the western portion of which is cut off by the dislocation known as the Hayes Fault. On the western side of the fault, however, the Netherton anticline is exposed, and the southern portion of this terminates in a curious and abnormal manner.[1] The probability of an original connexion between the folded measures above described and the Netherton anticline may, therefore, be inferred.

The productive Coal Measures in the neighbourhood of the three mines above named are overlain by sandstone-rocks which do not participate in the folding. The beds of the Witley Group in the Lutley Valley are almost horizontal, as also are the beds of the Hasbury Group on Hodge Hill. The beds of the Witley Group in the Colman-Hill area dip uniformly east-south-eastwards at a moderate angle, even where the coal below rises westwards at 1 in 3. The relations between the two series are clearly unconformable, while the Old-Hill Marls which should intervene are greatly attenuated or wholly absent.

To account for this purely local unconformity, I would postulate the formation of a continuous anticline, extending from Wassel Grove to Netherton, in early Upper Carboniferous times. This may well have occurred in the period represented by the Blackband Series of North Staffordshire, which series is not found locally. The attenuation of the Old-Hill Marls, of the Passage-Beds, and of the Witley Group (at Wassel Grove and Ham Dingle) may thus have been produced by overlap.

The second unconformity occurs at the summit of the Halesowen Series. A reference to the accompanying map (Pl. XLIV) will show that the Keele Series rests upon the various members of the Hasbury Group (see p. 447) from Ham Dingle to Hayley Green, and upon the Illey Group from Hagley Wood eastwards. The outcrop of the Illey Group is wholly confined to the area bounded on the west by the buried anticline at Wassel Grove, and on the

[1] 'The S. Staffs. Coalfield' Mem. Geol. Surv. 2nd ed. (1859) p. 154.

north by the flexure noted on p. 444. From the attenuated condition of the blue clay seen in the new quarries at Hasbury (p. 445), the beds of this group would appear to have been formed in a shallow basin opening southwards. The necessary conditions would be produced by a slight additional uplift of the buried anticline and

Fig. 4.—*Section from Wassel Grove to Oldenhall Colliery.*

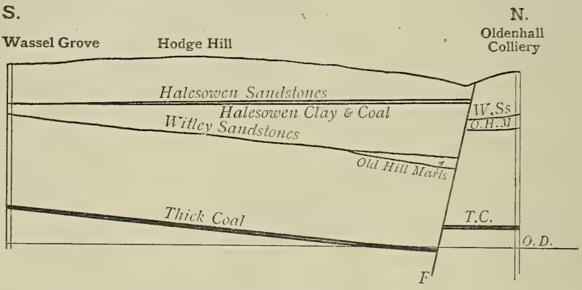
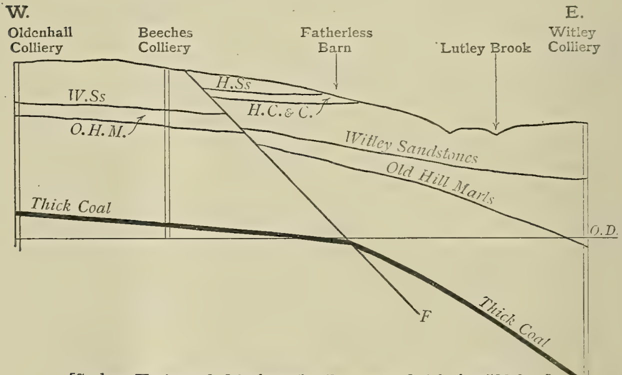


Fig. 5.—*Section from Oldenhall Colliery to Witley Colliery.*



[Scales: Horizontal, 3 inches=1 mile; vertical, 1 inch=500 feet.]

the formation of the flexure already mentioned. This unconformity also appears to be of purely local extent.

The relations between the Keele Beds and the Permian do not come within the scope of this paper; but I believe that unconformable relations will be found, as the various beds are traced from south to north.

VII. The Petrified Wood at Witley.

My attention was directed, some two years ago, by Mr. F. Jew, to some remarkable fossil wood found in the cutting along the mineral railway to Witley Colliery. When first seen, the lower slopes of the cutting appeared to be strewn with chips and splinters of wood. These were at length traced to some score of logs and other pieces embedded in the sandstone cliffs, and projecting at various angles from both sides of the exposure. These are all found in a prostrate position, and are clearly overlain and surrounded by undisturbed sandstone (Pl. XLIII).

The majority of the logs appear to have suffered attrition before coming to rest, and, judging from their appearance, also while undergoing petrifaction. Two logs, however, show the entire circumference, being surrounded by a quarter of an inch of bright brittle coal. One of these, exposed in transverse section only, is shown in Pl. XLIII, fig. 1. It is embedded in a large concretionary ballstone of dark, ferruginous, but highly calcareous sand, and measures 10 and 12 inches respectively in vertical and horizontal diameters. The second is shown in fig. 2 of the same plate. It has been exposed for a length of 6 feet, and it has a diameter of 16 or 17 inches. The cavity seen at the right-hand end of the log supplied a block measuring 1 cubic foot, which has been cut and polished so as to show the nature of the tissues. From this log, branch-like impressions, which, however, have lost the woody fibre, ramify through the sandstones to a distance of 10 or 12 feet. Well-preserved pith-casts of *Calamites* and other plant-remains have been found in actual contact with the log, and are described by Dr. Arber in the appendix (pp. 454 *et seqq.*).

My own work in connexion with the petrified wood consists in the selection and preparation of specimens, the tracing of the logs *in situ*, and the establishment of their Upper Carboniferous age. The age of the petrifactions is indicated by the following facts:—

The logs are buried naturally in a prostrate position. They have manifestly drifted into their present resting-place at the same time as the sediments which now form the sandstone rocks. That resting-place is in thickly-bedded, undisturbed, stratified sandstones of Upper Carboniferous age, in all respects like those of the surrounding country. The cutting is almost at the summit of a high natural bank, at the foot of which the Lutley Brook falls in a series of miniature cascades towards the River Stour. Its height above O.D. is 350 feet, and the section occurs in the very heart of a district which has suffered pronounced denudation in post-Glacial time, inasmuch as the nearest Glacial drift occurs on the sides of the Clent, Frankley, Quinton, and Blackheath Hills at levels never below 560 feet.

The petrifying material is calcite, which occurs in crystalline form in the rock-crevices, and also ramifies in veins through the mass of the logs.

EXPLANATION OF PLATES XLIII & XLIV.

Plate XLIII.

Fig. 1. Petrified log embedded in concretionary ballstone (3 feet in diameter) of ferruginous calcareous sandstone, at Witley Colliery, Halesowen. The vertical diameter of the log is 10 inches; the entire circumference is invested with a coaly rind.

2. Petrified log in Witley Colliery railway-cutting. Exposed length = 6 feet; vertical diameter = 16 inches. The entire circumference is invested with a coaly rind.

Plate XLIV.

Geological map of the Halesowen Sandstone area of the South Staffordshire Coalfield, on the scale of 3 inches to the mile, or 1 : 21, 120.

VIII. Appendix.

On the Structure *of* *Dadoxylon kayi*, sp. nov., *from the* Halesowen Sandstone *at* Witley (Worcestershire). By E. A. Newell Arber, M.A., Sc.D., F.G.S., Demonstrator in Palæobotany in the University of Cambridge.

During the summer of 1912 I had an opportunity, thanks to the kindness of my friend, Mr. Henry Kay, of inspecting the remarkable series of petrified trunks discovered by him *in situ* in the Halesowen Sandstones, exposed in a mineral railway-cutting at Witley Colliery in the Lutley Valley, near Halesowen (Worcestershire). The sandstones also contain a great abundance of plant-fragments, associated with the above-mentioned stems, among these being pith-casts of *Calamites suckowi* Brongn., *C. varians* Sternb., and *Cordaites (Artisia) approximatus* Brongn., as also impressions of the stems of *Lepidodendron* sp. Impressions of many other obscure and fragmentary portions of bark or of the woody tissues of stems or branches also occur, but the coarse nature of the sandy matrix renders them too indistinct to warrant determination.

The large trunks of the trees, described in Mr. Kay's paper, have in some cases a diameter of 40 centimetres. The woody tissues are alone preserved. The bark and other more external tissues are either absent, or represented only by a thin film of coal. So far as I could judge from an examination of the specimens *in situ*, the pith appears to have been of very small diameter, the centre of the trunk consisting of a very narrow zone of softer and less compact material. Certainly no indication could be found of the presence of any large pith, or of a pith-cast similar to the *Artisia* (= *Sternbergia*) pith-casts of *Cordaites*. A further examination of the polished surfaces of portions of these trunks confirms this conclusion. Such specimens exhibit no indications of annual rings of growth. The wood is very compact, and shows a large number of irregular, sometimes branched cracks filled with calcite.

The preservation, in calcite, of the structure of the wood is extremely good, and will bear comparison with much of the 'coal-

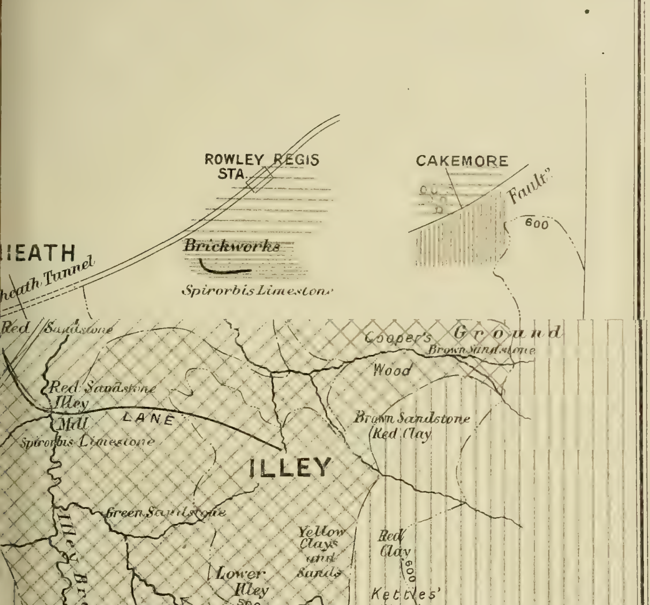
Fig. 1.—Petrified log embedded in ferruginous calcareous sandstone, Witley Colliery.

Fig. 2.—Large petrified log in Witley Colliery railway-cutting.

H.K. Photo.

Bemrose, Collo, Derby.

COALFIELD.



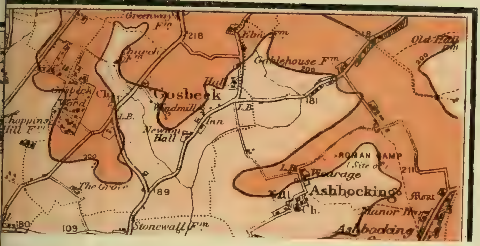
Weller & Graham. Ltd Litho, London

Map of the Halesowen Sandstone Area of the South Staffordshire Coalfield.

Weller & Graham Ltd Litho. London

GIPPING VALLEY,

ANCE OF BEDS OCCURS.



SCHEME

above O.D.

" "

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e geological strata (as shewn by sections
approximately the direction of the impingement
strike of the folds, etc.
e 100-foot contour, south-east of Sudbury.

v Map, with the sanction of the
and Fig.3 from Sheet 206.)

Fig. 3. CONTOURED MAP OF THE STOUR VALLEY (UPPER PART),

SHOWING PROJECTING SPURS WHERE DISTURBANCE OF BEDS OCCURS.

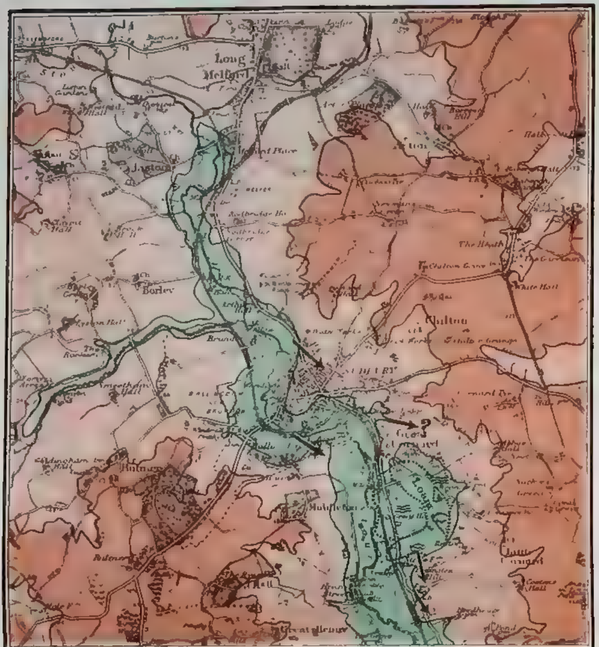


Fig. 2. CONTOURED MAP OF THE BRETT VALLEY,

SHOWING PROJECTING SPURS WHERE DISTURBANCE OF BEDS OCCURS.

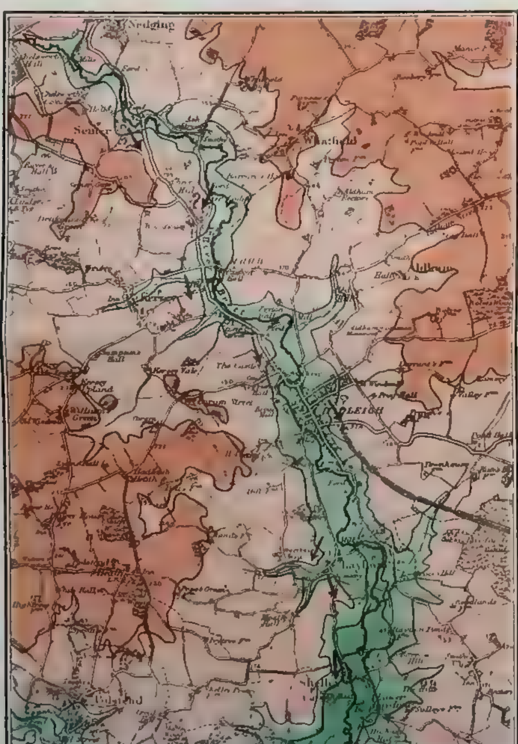
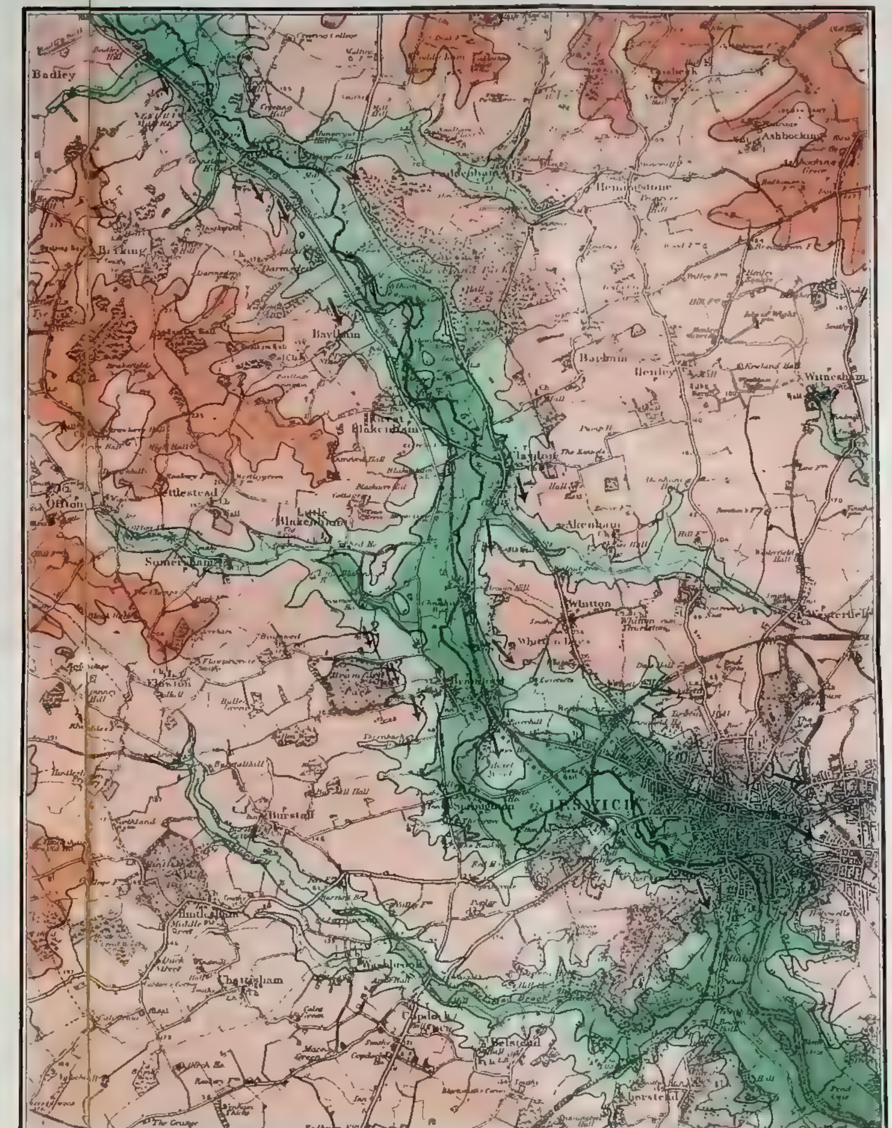


Fig. 1. CONTOURED MAP OF THE GIPPING VALLEY,

SHOWING PROJECTING SPURS WHERE DISTURBANCE OF BEDS OCCURS.



INDEX TO COLOUR-SCHEME

- 200 to 300 ft. above O.D.
- 100 to 200 feet
- 50 to 100 feet
- 0 to 50 feet

Scale, 1 Inch to 1 Mile.

The arrows indicate the position of marked glacial disturbance of the geological strata (as shown by sections or outcrops) upon the spurs projecting into the valleys. The arrows shew approximately the direction of the impingement of the ice of the valley-glaciers, determined as far as possible from the strike of the folds, etc.

In Fig. 3 a little of the superficial geology is inserted in the bay of the 100 foot contour, south-east of Sudbury.

(The above Maps are reproduced from the 1-inch Ordnance Survey Map, with the sanction of the Controller of H.M. Stationery Office: Figs 1 & 2 from Sheet 207 and Fig. 3 from Sheet 206.)

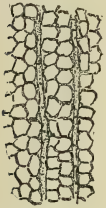
Fig.3.CONTOURED MAP OF T

SHOWING PROJECTING SPUR

ball' material. Attempts have been made to obtain sections through the pith, but without much success, for the preservation appears to be less perfect and compact in this region. The material here tends to crumble, and to break up, and for this reason no very reliable or definite information can be obtained with regard to the nature of the pith or the structure of the adjoining tissues.

A transverse section of the stem (fig. 6) shows that true rings of growth are absent, though false rings, impersistent when traced laterally, frequently occur. These are probably due to imperfections in the preservation, and doubtless were not originally a natural feature.

Fig. 6.—Dadoxylon kayi, *sp. nov. Transverse section, showing the tracheides with two medullary rays.* × 46.



The wood is very dense (fig. 6), the tracheides as seen in transverse section being small, from 0·037 to 0·051 mm. across, and more or less rectangular or square in form. Bordered pits are sometimes seen on their walls. A marked feature, however, of the wood is the great abundance of the uniseriate medullary rays. One ray sometimes occurs between each row of tracheides, and often between each two or three rows. In other cases a larger number of rows are frequently included between two rays.

Fig. 7.—*Radial section of* D. kayi, *showing the tracheides, with, in some cases, multiseriate bordered pits on the radial walls, and a single medullary ray, many cells in height.* × 46.

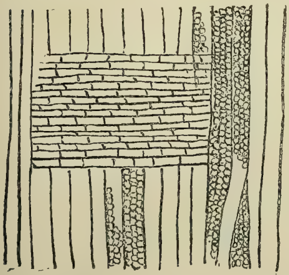


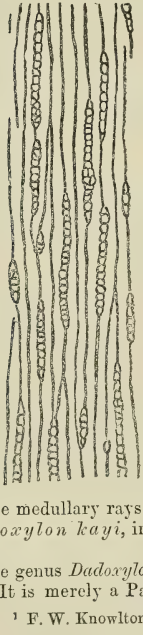
Fig. 8.—*A greatly enlarged sketch of part of a tracheid of* D. kayi, *as seen in radial section, with three rows of alternating bordered pits.* × 387.

In radial section (fig. 7) the tracheides are seen to be very long, and they measure 0·05 mm. across. The pits on their radial walls

are in some cases clearly seen (fig. 8, p. 455). They are bordered pits, usually arranged in more than one row, two rows being frequently observed; while in some cases three alternating rows (fig. 8) occur. The medullary rays (fig. 7, p. 455) vary greatly in height, as is more clearly seen in tangential sections.

In tangential sections of the wood, no pits are usually seen on the walls. The abundance and great variation in the height of the medullary rays (fig. 9) is seen to great advantage in these sections. They vary from one to twenty-seven elements in height, and measure in height between 0·06 and 0·66 mm. Occasionally, a ray (fig. 9, below) becomes partly biseriate.

Fig. 9.—*Tangential section of* D. kayi, *showing the tracheides with the medullary rays between them.* ×46.



From the above description it is clear that the structure of the Witley wood agrees in its general characters with that of the modern Conifer *Araucaria*. The absence of a discoid pith obviously removes it from close proximity to *Cordaites*. It has been long known that fossil woods of this type occur widely, both in the Palæozoic and in the Mesozoic rocks, as well as in more recent sediments. It has been suggested, however, by Felix, and later by Knowlton,[1] that it would be well to group together such of these woods as are of Palæozoic age into the genus *Dadoxylon*, and to reserve the term *Araucarioxylon* for those which are of Mesozoic or later age. This convention has since been widely adopted, one reason being that the evidence at present available for the existence of the Araucariæ in Palæozoic times is very unsatisfactory; and further, it may be that these Palæozoic woods represent a general type of structure common to more than one race of Conifers in the past.

I therefore here refer the Witley specimens to the genus *Dadoxylon*; and, since these woods in their specific characters appear to me to differ from those previously described, especially as regards the abundance and height of the medullary rays, I have also referred them to a new species, *Dadoxylon kayi*, in honour of their discoverer.

The genus *Dadoxylon* is at present loosely defined, and purposely so. It is merely a Palæozoic wood resembling that of a modern

[1] F. W. Knowlton, Proc. U.S. Nat. Mus. vol. xii (1889) p. 606.

Araucaria. The chief botanical interest of these specimens, however, lies in the fact that we have here further evidence of the occurrence of Coniferæ in the higher Coal Measures of the Midlands. The leafy twigs of *Walchia* are very rare fossils in the British Coal Measures, but they have been recorded by Dr. Kidston from two or three localities in South Staffordshire. It is true that no such shoots have been recognized at Witley, and there is at present no direct evidence to correlate these woods with *Walchia.* But these woods were undoubtedly also Coniferous, though not necessarily Araucarian, nor with certainty allied to *Walchia.*

These stems are perhaps of greater geological than strictly botanical interest. It need hardly be pointed out that practically all the petrified material known from the British Coal Measures is derived solely from the calcareous nodules or ‘coal-balls’ of the Pennine coalfields, and from Lower Coal-Measure rocks. The exceptions can be counted on the fingers of one hand. There are, it is true, the extraordinary breccia-petrifactions, as yet not fully described, recorded a few years ago by Mr. Lillie[1] from the Transition Coal Measures of Bristol. Of greater importance in the present connexion is *Dadoxylon spenceri* Scott,[2] from the Lower Coal Measures of Halifax, which occurred as an isolated petrifaction. This is, I believe, the only other species of this genus hitherto recorded from Britain, and it is quite distinct from that which is described here.

The occurrence of isolated petrifactions, free from any calcareous matrix, in the Lutley Valley is interesting geologically, because on the Continent, especially in the Permian rocks, such trunks are of frequent occurrence. In this country the conditions necessary for the preservation of woods in this manner appear to have recurred but rarely. I do not propose to enter here into any comparison with the fossil woods of the Permian rocks of Germany, described by Göppert and others. Attention may, however, be called to the remarkable fossil forests of the beds of that age in the neighbourhood of Chemnitz, in Saxony, the relics of which have been so carefully preserved and described by my friend Prof. Sterzel.[3] Most of these woods resemble *D. kayi* in type, and belong to the same genus.

Dadoxylon kayi, sp. nov.

Diagnosis:—Pith very small, not discoid. Wood without true rings of growth, tracheides small, 0·037 to 0·051 mm. across, dense, long, with one to three alternating series of bordered pits on the radial walls. Medullary rays very abundant, uniseriate or sometimes incompletely biseriate, varying from one to twenty-seven cells in height (0·06 to 0·66 mm.).

[1] D. G. Lillie, Geol. Mag. dec. 5, vol. vii (1910) p. 60.
[2] D. H. Scott, Trans. Roy. Soc. Edin. vol. xl, pt. 2 (1902) p. 357.
[3] J. T. Sterzel, xiv. Bericht Naturwiss. Gesellsch. Chemnitz (1896–1900) p. 3, and xv. Bericht *ibid.* (1900–03) p. 23.

Discussion.

Dr. Walcot Gibson welcomed the attention of local geologists to an interesting tract of country made classical by the work of Murchison, Ramsay, and Jukes. If a thin coal was taken as an index of position in a sequence, it should either possess very marked characters, or it should be associated with strata of a pronounced type and readily recognizable from place to place. It was difficult, if indeed not impossible, to state definitely the relation of the Halesowen Sandstone Series to the Old-Hill red clays. The unconformity of the Keele Beds to the underlying grey measures needed stronger confirmation, since it was directly opposed to the evidence in adjacent areas and to that obtained in mining.

Dr. Arber, in congratulating the Author on the results of his study of this portion of the South Staffordshire Coalfield, drew attention to the excellent preservation of the Witley *Dadoxylon* and the rarity of this fossil in the Coal Measures. He pointed out that the absence of annual rings, a feature in which these stems agree with almost all the known coniferous woods of the Permo-Carboniferous of the Northern Hemisphere, indicated the existence of a uniform, genial, but not necessarily tropical climate. The Halesowen Sandstones were essentially a grey series intercalated between two sets of red measures; but whatever may have been the conditions which gave rise to the red rocks, the fossil woods of the Halesowen Sandstones indicate that the climatic conditions did not at that stage differ markedly from those of the productive Coal Measures.

The Author, in reply to the first speaker, gave examples of the manner in which he had traced the outcrop of the Halesowen Coal and Clays. The evidence for unconformity was that bright-red marls of the Keele Series and Permian rested sometimes upon the Illey Group, and at others upon successive members of the (lower) Hasbury Group. The upper boundary of the Illey Group had not been defined in his paper, the line shown on the existing Survey-maps being for the present accepted. The Old-Hill Marls passed conformably upwards into the Halesowen Series, a typical instance being found on Mucklow Hill. In conclusion, he expressed his thanks for the kind reception accorded to his paper.

21. *The* Volcanic Rocks *of the* Forfarshire Coast *and the* Associated Sediments. By Albert Jowett, D.Sc., F.G.S. (Read June 11th, 1913.)

[Plates XLV & XLVI.]

Contents.

I. Introduction.

The earliest description of the volcanic rocks of Lower Old Red Sandstone age, which are so admirably exposed on the coast of Forfarshire, we owe to the Rev. John Fleming,[1] whose observations were in a remarkable degree unprejudiced by the theories prevalent at the time when he wrote.

A fuller account of the rocks as they appear in the field is given by Sir Archibald Geikie in his 'Ancient Volcanoes of Great Britain;'[2] but no attempt has been made, up to the present, to describe the rocks of this locality as they appear under the microscope, although similar rocks in adjoining areas[3] have been so dealt with.

The Geological Survey 1-inch maps[4] clearly indicate the occurrence of a great anticline, a continuation of the Ochil Axis, which runs in a general east-north-easterly direction, passing out to sea near Montrose,[5] where exposures of the oldest lavas may be seen. On following the coast southwards from Montrose, one meets with higher beds in the volcanic series; these extend as far as the Lunan-Bay sands, beyond which a newer and higher series of lavas

[1] 'On the Mineralogy of the Redhead in Angus-shire' Mem. Wern. Nat. Hist. Soc. vol. ii, pt. 2 (1815–18) p. 339.

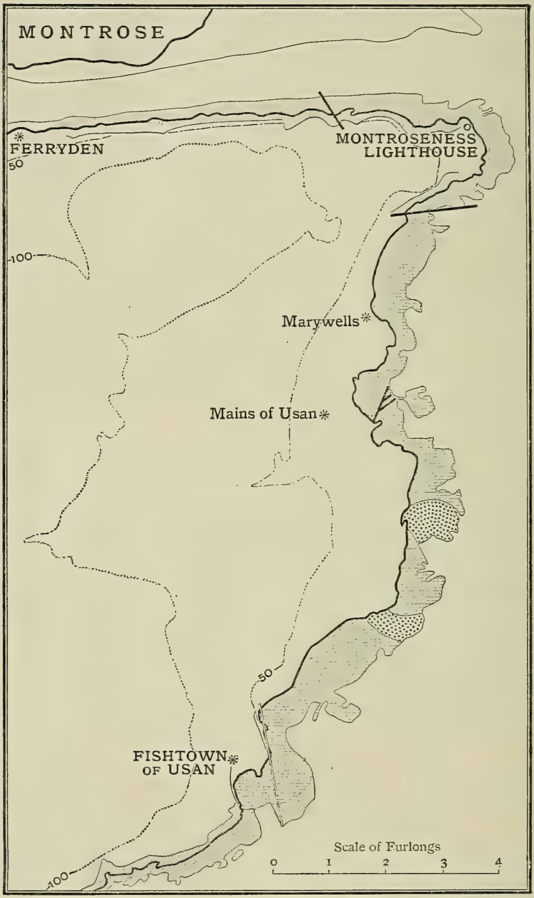
[2] Vol. i (1897) pp. 299–301.

[3] 'The Geology of Central & Western Fife & Kinross' Mem. Geol. Surv. 1900; 'The Geology of Eastern Fife' Mem. Geol. Surv. 1902; R. Campbell, 'Geology of S.E. Kincardineshire' Geol. Mag. dec. 5, vol. viii (1911) p. 69.

[4] Forfar, Sheet 57; Arbroath, Sheet 49.

[5] Sir Archibald Geikie, 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 299.

Fig. 1.—*Geological map of the coast, from Montrose to Fishtown of Usan.*



Enstatite-basalt.

Enstatite-olivine-basalt.

Olivine-basalt with olivine-phenocrysts.

Lower Old Red Sandstone sediments, including true conglomerates interbedded with lavas.

Porphyrite-dykes.

forms the promontory that juts out eastwards on the south side of the Bay. These lavas are succeeded by sandstones, all dipping consistently south-eastwards.

Broadly speaking, therefore, the field-relations of these rocks are quite simple. When, however, we descend to detail, the petrological similarity of the different lava-flows, their lenticular character, as also the lenticular character of the conglomerates and sandstones which are found among them, make it very difficult to ascertain the precise effects of the faults that frequently occur, and consequently to obtain a correct idea as to the order in which the lava-flows succeeded one another.

The excellence and accessibility of the cliff-sections between the Red Head and Lunan Bay has led to an attempt to investigate their structure in greater detail than has been found possible in dealing with the coast between Lunan Bay and Montrose.

II. Field-Relations of the Rocks.

(*a*) Montrose to Lunan Bay.

About a quarter of a mile south-west of Montroseness Lighthouse, a fault occurs, separating two types of lava which can be distinguished one from the other quite easily.

North of the fault, and extending round the coast as far as Ferryden, the volcanic rocks nearly all contain numerous lath-shaped felspar crystals, which are particularly obvious on weathered surfaces. These rocks[1] may be termed enstatite-olivine-basalts. In colour they vary considerably, black or grey-black predominating, though some are greenish, purple, or brownish-red. The lavas are individually of no great thickness, rarely exceeding 10 or 12 feet, and are bedded in a very irregular manner. At the base of each sheet occurs a few inches of compact, almost flinty rock, which is moulded upon the irregular surface of the rock beneath. Above, the rock becomes obviously coarser in grain, and this passes upwards into very slaggy purplish lava, usually full of green amygdales, and much weathered.

The amygdaloidal lava is generally much fissured, the fissures and larger cavities being filled with hard, fine-grained, greenish or brownish-red sandstone, which often penetrates into the more compact lava below, where the fissures become less numerous and thin out. The sediment frequently expands into sheets, usually not more than a few feet across, at the surface of the lava.

The regular recurrence of these characters, which are typical of the lavas of Lower Old Red Sandstone age,[2] suggests the gradual accumulation of sheets of rock solidifying from the molten state under conditions that allowed of the contemporaneous deposition

[1] Petrographical descriptions of these and other rocks named in this section are given later in § III, pp. 472–75; § IV, pp. 475–77.

[2] Sir Archibald Geikie, 'Ancient Volcanoes of Great Britain' vol. i (1897) pp. 263–347.

of fine sediment, probably in water of no great depth, as the sediments are generally current-bedded.

Near the fault mentioned above (p. 461), a highly-contorted layer of sediment, coarser than usual, was found interbedded with the lava. This is composed almost entirely of volcanic débris, and is probably one of the finer-grained beds associated with the volcanic conglomerates.

South of the fault, the felspar-phenocrysts so characteristic of the lavas met with on the north and west are no longer found—the new rocks being generally fine-grained, with obvious red phenocrysts representing pseudomorphs after olivine. These rocks are olivine-basalts. This type of lava extends southwards continuously for a mile and a quarter, as far as Fishtown of Usan.

Up to this point the rocks are exposed only between the tidal limits, the low cliffs being here grassed over. Excellent horizontal sections, however, are exposed; and, where the harder rocks have resisted the action of the waves, crags 10 or 12 feet high provide good vertical sections. A few faults are traceable, but I could find no evidence that their throw is considerable.

The upper portions of the lavas are amygdaloidal, much fissured, and covered by a variable thickness of slaggy fragments, so that, with the sediment deposited in the crevices, they resemble conglomerates in appearance. In some cases, the rock-fragments are rounded, forming true conglomerates, often of no great thickness, intercalated in the series. Sometimes the compact base of a lava-stream rests directly upon amygdaloidal or even compact lava with sandstone-filled fissures, without any intervening 'conglomerate,' probably indicating that the loose material usually present has been removed and deposited a little distance away as a true conglomerate.

The frequent redness of such slaggy and conglomeratic beds has been attributed by Sir Archibald Geikie [1] to oxidation during the lapse of time between two successive outflows of lava.

The compact lavas vary much in colour, the fresh rocks being almost black, but passing, with varying degrees of weathering, through shades of grey, purple, brown, and red to a lilac tint.

A quarter of a mile south-east of 'Mains of Usan,' much-weathered lavas are clearly overlain by a massive conglomerate full of well-rounded boulders measuring up to 3 feet in diameter. At the base of the conglomerate occurs a non-persistent layer of red sandstone, sometimes 18 inches thick.

The matrix of the conglomerate consists of a coarse purplish sediment, which, when microscopically examined, is found to be composed almost entirely of small fragments of different kinds of volcanic rock. The boulders in the conglomerate, though all of volcanic origin, are not all of the same type, some exhibiting porphyritic felspars.

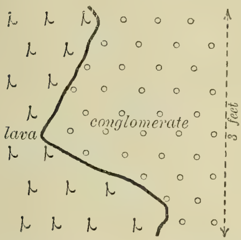
At the surface of the conglomerate is a layer of 12 to 18 inches

[1] 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 301.

of sediment, similar to the matrix of the conglomerate. The conglomerate dips southwards under an escarpment of compact lava, 10 to 15 feet high. A number of spheroidal masses of volcanic rock about 2 feet in diameter, which exhibit concentric amygdales where broken across, occur in the lower portion of this lava. They are embedded in compact lava, and are the best examples of 'pillows' that I have observed along this coast, although a rude pillow-structure is not uncommon. The upper portion of the lava becomes more amygdaloidal, though lenticular amygdaloidal patches occur within the more compact mass, and towards the top it is of a brick-red colour and much intersected by fissures filled with green sandstone.

A somewhat remarkable exposure of conglomerate occurs about half a mile north-east of Fishtown of Usan. The conglomerate rests on an irregular surface of volcanic rock, apparently filling in a network of valleys. The junction between the two is sometimes vertical and quite irregular in plan, though not faulted, one example appearing as shown in the appended fig. 2.

Fig. 2.—*Plan of the junction between conglomerate and lava, north-east of Fishtown of Usan.*



All the boulders examined in this conglomerate were volcanic rocks of a type characterized by felspar-phenocrysts.

The cliffs commence at Fishtown of Usan, and continue almost without a break as far the sands of Lunan Bay.

Immediately east of Fishtown a great wall of rock rises about 50 feet above the shore, and is separated by a narrow gap from the cliff. It consists partly of a dyke[1] and partly of the lavas into which the dyke was intruded. The dyke is about 6½ feet wide, and is a brownish-red rock with fairly large felspar-phenocrysts and some green amygdales. This rock is a porphyrite, and is easily distinguished by its felspars from the lavas into which it is intruded, as also by the absence of the sandstone-filled fissures and clinker-beds which are so characteristic of the latter.

West of the harbour of Fishtown of Usan, the olivine-basalts are succeeded by a type of volcanic rock which is characterized by large plagioclase-phenocrysts, as also abundant red and green amygdales.

This new type of lava, an enstatite-basalt, is a famous hunting-ground for agates and other secondary minerals,[2] and the upper portion of each sheet is seamed by fissures filled with pale-

[1] Geol. Surv. 1-inch map, Sheet 57.

[2] M. F. Heddle, 'Mineralogy of Scotland' 1901, vol. i, pp. 75–76, 106, 131, & vol. ii, pp. 140, 146.

green sandstone. As the strike is here parallel to the coastline, not many different lava-flows are exposed.

At the Rock of St. Skae occurs another dyke[1] of porphyrite, which is intruded in close proximity to an important fault. The dyke and silicified fault-breccia together form a vertical wall of rock

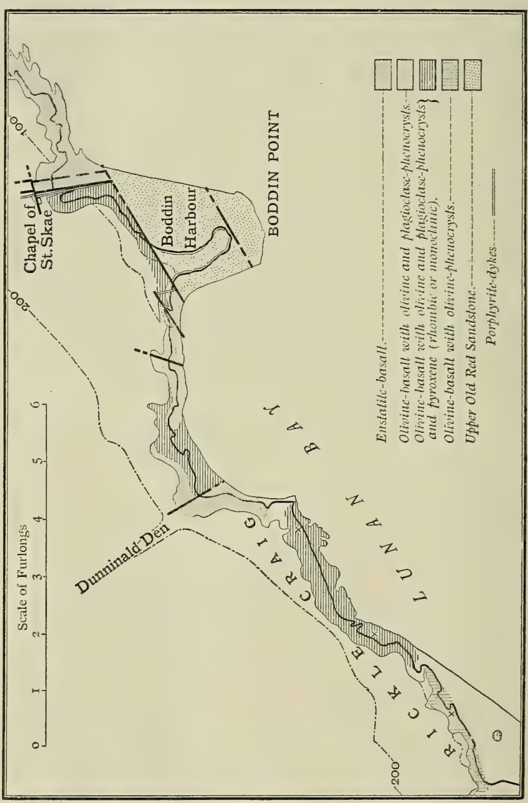


Fig. 3.—*Geological map of the coast, from near Fishtown of Usan to the Lunan-Bay sands.*

rising from the beach to a height of over 100 feet, and projecting from the cliff southwards across a small bay which is flanked on each side by steep cliffs. The 'Rock' has been tunnelled by the

[1] Geol. Surv. 1-inch map, Sheet 57.

waves a little below high-water mark, where it is about 30 feet wide. The dyke is about 16 feet wide. The eastern side of the 'Rock' is horizontally slickensided over a large area, and horizontal slickensides may also be seen in a cleft along the ridge running in a direction north 6° west. In the cliff on the east, and cutting across the 'Rock' just behind the Chapel, another fault occurs, which is almost exactly at right angles to this (north 82° east), apparently displacing it, and is slickensided almost vertically, throwing the rocks on its southern side some little distance westwards horizontally. About two-thirds of the way across the little bay east of the 'Rock' more fault-breccia may be seen at about high-water mark, and this fault is exactly parallel to the trend of the 'Rock' (north 6° west).

The difference in character of the vein-stuff[1] parallel to these two sets of faults also furnishes evidence that the east-and-west fault is of later date than those running north and south. The dyke is displaced by the east-and-west fault movement, and is brecciated by both faults. Moreover, in a cliff-section in the gully north of the Chapel of St. Skae, the dyke appears flanked on each side by lava, the main fault-movement (indicated by breccia) having occurred in the lava. It is evident, therefore, that the intrusion took place prior to the initiation of the older north-and-south faults.

From the Rock of St. Skae to Boddin village, the lavas are olivine-basalts, which contain plagioclase-phenocrysts and monoclinic as well as rhombic pyroxenes. Excellent sections of amygdaloidal lavas with sandstone-filled fissures may be seen in the cliffs. On the shore in Boddin Harbour near high-water mark, a fault which throws calcareous Upper Old Red Sandstone against the volcanic rocks is well displayed in horizontal section. The excellent vertical section of the same fault where it emerges north-west of Boddin Point, and the Upper Old Red Sandstone itself, have been well described by Dr. G. Hickling.[2] The surface of the sandstone is slickensided, the striations inclining at 10° from the vertical, and therefore the total effect of the fault would be, not only to throw the sandstone down southwards, but also to move it westwards to a slight extent. Parallel slip-planes occur in the sandstone for some distance south-east of the main fault; and, even at the extremity of the headland 300 yards away, there is a well-marked fault which trends exactly in the same direction.

Some 50 yards west of the corner of the bay where the large fault emerges, a porphyrite-dyke is intruded in the lavas in the cliff and on the shore. It trends north 8° west, thus being practically parallel to the St. Skae dyke, which it closely resembles; although the lavas are not faulted alongside it as in the latter case. The dyke varies in width from 3 to 6 feet, and is markedly finer in grain for about 3 inches from each of its boundary-planes.

[1] See below, p. 480.

[2] 'The Old Red Sandstone of Forfarshire, Upper & Lower' Geol. Mag. dec. 5, vol. v (1908) p. 404.

About 15 yards from the cliff, the dyke is cut off abruptly against the Upper Old Red Sandstone by the main fault, which is continued along the shore. A smaller fault in the lava, parallel to the main fault, and nearer to the cliff, throws the dyke 18 inches horizontally westwards. This dyke is unquestionably of Lower Old Red Sandstone age. Some 50 or 60 yards west of it another important fault occurs, which causes a small inlet and trends north 57° east—almost parallel to the main fault (north 62° east). We see, then, that a number of faults having the same general trend, and evidently the result of closely-related earth-movements —probably all throwing down south-south-eastwards, and effecting a slight horizontal westward movement of the rocks on their southern sides—occur between the Rock of St. Skae and the bay west of Boddin Point.

Now, the general trend of the coastline, from Fishtown of Usan to the Lunan-Bay sands, is closely parallel to the general trend of this system of faults, and it seems very probable that the similarity is more than a mere coincidence. The significance of these facts will be more apparent when we come to consider the system of faults parallel to the line of cliffs on the south side of Lunan Bay.

To return to the volcanic rocks west of Boddin Point. Nearly all are very much weathered, some too much so for proper determination. The one against which the Upper Old Red Sandstone is thrown is a much-weathered amygdaloidal rock with felspar-phenocrysts, and is probably an olivine-basalt. On the northern side of the fault, in the small inlet 100 yards farther west, an olivine-basalt without felspar-phenocrysts occurs, but this is immediately overlain by a type containing obvious felspars. There is a remarkable development of the sandstone-filled fissures and clinker-beds among all the lavas in these cliffs. Usually, well nigh half of the total thickness of each lava-sheet is composed of such material; but, sometimes, the lava is so completely penetrated by veins of sandstone that very little unbroken compact volcanic rock remains. The total thickness of a complete sheet in this neighbourhood is only about 15 feet on the average. Farther west much thicker sheets occur, especially near the outlet of Dunninald Den. Here an important north-and-south fault throws down westwards a thick sheet of enstatite-basalt, which appears to extend without a break from high-water mark nearly to the top of the cliffs. A rock very similar to this occurs on the eastern side of the 'Den,' about a third of the way up the cliff, where it rests upon olivine-basalt.

I could find no trace of the 'dyke' marked on the Geological Survey 1-inch map, but a peculiar silicified breccia occupies the position of what I take to be the fault mentioned above.

The cliffs (Rickle Craig) from south of Dunninald Den to the Lunan-Bay sands are high and rugged, exhibiting some fine examples of the effects of marine erosion on rocks of this character.

All the accessible rocks appear to be olivine-basalts, the type with felspar-phenocrysts disappearing westwards. The outcrop of the lavas terminates as a cliff, against which Glacial deposits, beaches above the present level, and blown sand are banked up. I could find no evidence of the relations between the lavas and any other solid rocks in the vicinity.

(*b*) Lunan Bay to the Red Head.

From Lunan Bay to the Red Head, all the volcanic rocks are olivine-basalts, between which, with one exception, it is not easy to distinguish in the field. The exceptional type has obvious felspar-phenocrysts, and is exposed in the lower part of the cliff for about 300 yards west of Ethie Haven. No dykes have been found in this series.

There seems to be no doubt that a considerable thickness of sandstone—Dr. Hickling's Cairnconnan Series[1]—is intercalated between the lavas on the south and those on the north of Lunan Bay. For some distance west of Lunan Bay the solid rocks are buried under superficial deposits, but in the south-western corner of the bay several outcrops of sandstone of a different kind occur in the cliff and on the beach.

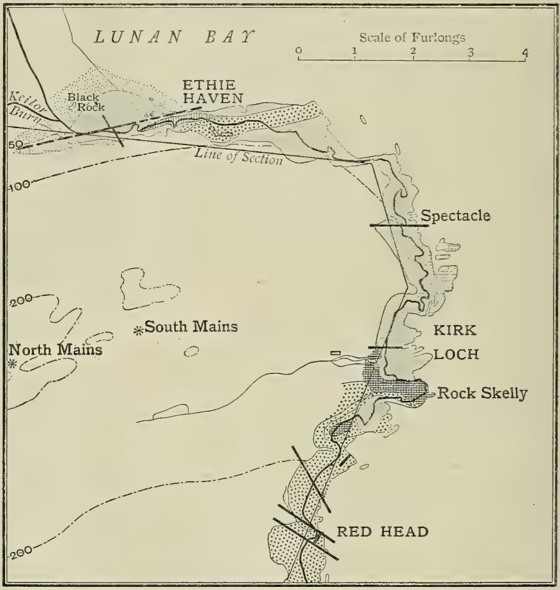
Near the base of the cliffs at Bird's Knap, immediately south of the mouth of Keilor Burn, is an exposure, almost obscured by vegetation, of red and yellow sandstone resting upon a breccia containing angular red sandstone. Black Rock, which emerges from the sand on the shore about 100 yards north-east of this exposure, is a mass of breccia, composed almost entirely of angular red sandstone, but containing a few small rounded boulders of volcanic rock. South-eastwards, the sand on the shore gives place to a bare rock-surface consisting of much-weathered volcanic rock, which rises here and there into stacks of harder but still much-weathered basalt. No sandstone appears, except the usual sediment intercalated with the lavas. South-east of Bird's Knap the cliff rises, but continues to be grassed over until it bends sharply eastwards, where it is seen to consist entirely of basalt. The lower part of the cliff is well-slickensided for some distance, and clearly indicates the presence of a fault; this appears in a projection of the cliff farther west, and eastwards runs across the beach. The fault has a trend about 15° north of east, hades northwards at an angle of 19°, and the slickensides incline westwards at an angle of 20° from the vertical. There is a good deal of smashing parallel to this fault, which is marked by parallel veins of calcite wherever a section occurs in a direction at right angles to the cliff. It is quite clear that the trend of the cliff is largely dependent upon the direction of this system of faults.

About 200 yards east of the south-western corner of Lunan Bay, a mass of silicified fault-breccia (3 feet wide) stands out like a

[1] Geol. Mag. dec. 5, vol. v (1908) p. 400.

dyke from the cliff and above the beach. It marks the position of a fault which runs north 28° west, and hades westwards at an angle of 16°. This fault is obviously older than the east-and-west fault-system described above, for its fault-breccia is broken

Fig. 4.—*Geological map of the coast, from the Lunan-Bay sands to the Red Head.*



Olivine-basalt with plagioclase-phenocrysts and olivine in groundmass.
Olivine-basalt with olivine-phenocrysts.
Olivine-basalt with glomeroporphyritic aggregates of olivine, augite, and labradorite.
Lower Old Red Sandstone sediments, including true conglomerates interbedded with lavas.
Upper Old Red Sandstone.

across by a member of the latter, and the portion of fault-breccia on the northern side is thrown westwards a distance of 6 feet.

On the shore 300 yards west of Ethie Haven, and about half-way between high- and low-water marks, occur two large detached masses of red and yellow mottled sandstone resting on a sandstone-breccia. Some portions of the sandstone exhibit a beautiful poikilitic structure when broken, owing to the uniform crystallization

of the calcite-matrix over patches measuring a quarter to half an inch in diameter. The beach is covered with large boulders set close together, but its foundation appears to consist of volcanic rock, and some large stacks of basalt *in situ* stand out at low-water mark between these masses of sandstone and the sea. Some 50 yards farther north-east, an escarpment 150 yards long may be seen at exceptionally low tide. Its edge is almost horizontal, and strikes north-west and south-east. The rock consists of a well-bedded sandstone-breccia, dips north-eastwards at about 5°, and appears to rest upon a denuded surface of volcanic rock.

The close lithological resemblance between these sandstones and the Upper Old Red Sandstone of Boddin Point, coupled with (as Dr. Hickling informs me) their dissimilarity to any of the sandstones of the Cairnconnan Series, favours the opinion that they are of Upper Old Red Sandstone age, a probability which is strengthened by the marked unconformity that appears to exist between them and the lavas upon which they rest.

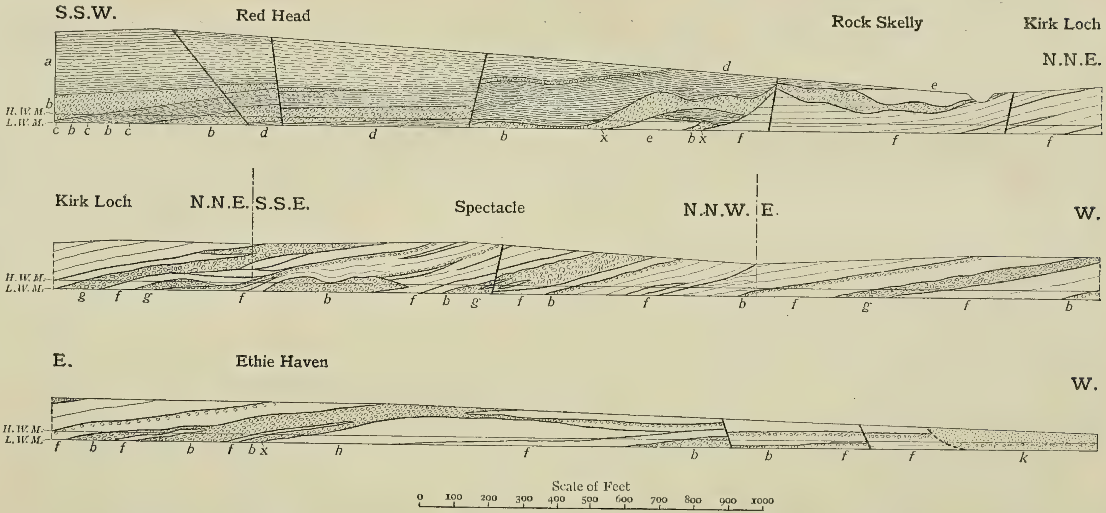
Further, it seems very likely that the mass of Upper Old Red Sandstone, which rises a little above high-water mark at Boddin, skirts the coast not far below low-water mark from Fishtown of Usan to the Lunan-Water estuary, being thrown down by the faults that run parallel to the coastline; also, that it continues under Lunan Bay and much of the drift-covered area on the west, reappearing in the cliff and along the shore south of Lunan Bay in close relation with another series of faults, which are cognate with those on the north side of the bay, and have a similar effect in determining the line of cliffs. It is significant that such an area of Upper Old Red Sandstone coincides remarkably in position with the Upper Old Red Sandstone which emerges here and there through the superficial deposits north of Montrose, and is possibly continuous beneath them. The same kind of feature is again repeated in the occurrence of Upper Old Red Sandstone at Seaton Bay, north-east of Arbroath.

An attempt has been made to represent, by means of the accompanying ideal section (fig. 5, p. 470), every important feature along the coast from the south-western corner of Lunan Bay to the Red Head. The rocks are so admirably exposed, that most of what is set down may be directly observed, little being the product of mere inference. This is more particularly the case with the part of the coastline trending from north to south outside Lunan Bay.

From what has already been said, it will be understood that the base of the series of lavas south of Lunan Bay is not exposed. How far they extend northwards under the cover of Upper Old Red Sandstone is merely a matter of conjecture. Inland they thin out, as represented on the Geological Survey map, towards the south-west. It is probable that they thicken north-eastwards, and ultimately unite with the lavas north of Lunan Bay, the intervening Cairnconnan Sandstones thinning out in the same direction.

The lavas succeed each other regularly, with the usual admixture of sediment in the upper portion of each sheet, until at Ethie Haven,

Fig. 5.—*Diagrammatic section along the coast from the Red Head to Ethie Haven and the south-western corner of Lunan Bay.*



Lower Old Red Sandstone.
- a = Red and grey sandstone.
- b = Coarse conglomerate: materials nearly all volcanic.
- c = Finer sediments: materials nearly all volcanic.
- d = Red shale, with bands of fine conglomerate.
- e = Olivine-basalt, with glomeroporphyritic aggregates of olivine, augite, and labradorite.

Lower Old Red Sandstone.
- f = Olivine-basalt with olivine-phenocrysts.
- g = Masses of slaggy lava cemented by fine sediment.
- h = Olivine-basalt with plagioclase-phenocrysts and olivine in the groundmass.
- x = Local unconformity.

k = Upper Old Red Sandstone: mottled red sandstone and sandstone-breccia.

they dip beneath a thick mass of very red conglomerate. This conglomerate rests upon more than one type of basalt, and it doubtless marks a stage when the eruptions were much less frequent and considerable erosion of the lavas took place. Its materials are very much weathered. At least two very fine-grained basalts are included within the conglomerate, one of which is well displayed immediately east of Ethie Haven at high-water mark. It forms an extremely-irregular lenticular sheet, and, where it thins out, appears to split into two or three layers which dovetail into the conglomerate. The upper surface of the conglomerate is irregular, sometimes dipping steeply under the lava which rests upon it. The lava is fine-grained, and breaks into thin plates near the junction.

In general appearance, the basalts met with above this horizon closely resemble the lavas already described.[1] Very rugged coast scenery results from the action of the waves in tunnelling through the soft amygdaloidal lava and conglomerate and preserving the more compact lavas, although sometimes a conglomerate is more resistant than the lavas.

On the eastern side of the promontory, where the coastline leaves Lunan Bay and turns abruptly southwards, is a series of amygdaloidal lavas having at its base a red conglomerate. Immediately above the conglomerate occurs a mass of big rounded blocks of scoriaceous lava, embedded partly in lava of a similar type and partly in finer conglomerate. This is another example of 'pillow'-lava.

Excessive weathering of the compact basalts seems to show itself in the development of calcite in felspar, pyroxene, and olivine alike, giving to the whole rock a pale coloration, almost white by contrast with the comparatively unaltered rock. Such rocks are generally found in association with red 'conglomerates.' Fine examples may be observed in the neighbourhood of the 'Spectacle.'

South of Rock Skelly, excellent sections occur, showing a true conglomerate, with large boulders of volcanic rock, resting upon a very irregular denuded surface of the underlying lavas. Along the shore, the waves are cutting away the softer conglomerate, and laying bare the hard stacks of lava buried beneath it.

At Rock Skelly, a thick sheet of hard lava fills in and covers the hollows and mounds which form the surface of the conglomerate.

The lower portion of this lava is very platy, the divisional planes preserving a rough parallelism with the irregular surface of the conglomerate, which is hardened at the contact and overhangs the softer conglomerate beneath it in the cliff. The main mass of the lava exhibits a rude columnar jointing, and although upwards of 30 feet may be seen in some sections, its original upper surface does not appear. There is little doubt, however, that the conditions which produced the conglomerate beneath it continued after its extrusion, and led to its partial removal by denudation before it was protected by further sedimentation. This is more likely because

[1] *Ante*, pp. 461, 462.

another rock, practically identical with it petrographically, and occupying a similar stratigraphical position (that is, with the same conglomerate below and above it), crops out at the foot of the cliff farther south. The upper portion of this lava is amygdaloidal.

The conglomerate preserves its hummocky surface in a very striking manner when it is buried in the overlying red sandstones, which first appear at the top of the cliff immediately south of Rock Skelly. The sandstone is current-bedded around the mounds, but quite evenly bedded above them, dipping away steadily southwards.

The conglomerate itself is by no means uniform in texture, sometimes including fairly thick bands of red sandstone and of finer conglomerate: these, however, were often partly removed by the stronger currents which brought the larger boulders that make up the coarser part of the deposit. On the whole, the conglomerate appears to thin out northwards.

Farther south, higher beds of red sandstone, shale, and conglomerate attain a great thickness in the cliffs, and all appear to contain more or less volcanic débris. The beds of conglomerate increase in thickness, and their boulders increase in size towards the south, consisting almost entirely of volcanic rocks with occasional angular and subangular pieces of red sandstone. They are covered by thick beds of sandstone, which, higher in the series, include pebble-beds of an entirely different character, containing a preponderance of well-rounded pebbles of quartzite, in addition to those of volcanic origin.

III. Petrography of the Igneous Rocks.

(*a*) Lavas.

(1) Petrographical types.—The distribution of the various types of lava is indicated on the sketch-maps (figs. 1, 3, & 4, pp. 460, 464, & 468).

The enstatite-basalt is the only type from which olivine is absent, and, although it occurs for a considerable distance along the coast north of Lunan Bay, it constitutes but a small fraction of the lavas between Montrose and the Red Head.

The olivine-basalts may be divided into two main groups, according as olivine occurs in the form of phenocrysts, or is entirely restricted to the ground-mass. The former group is the more abundant, the latter including two varieties only: one with enstatite and plagioclase-phenocrysts (near Montrose), and one with plagioclase-phenocrysts only (near Ethie Haven). The most abundant variety in the former group has, broadly speaking, no phenocrysts except olivine, augite occurring in the ground-mass with felspar and iron-oxides; although in other varieties phenocrysts of (1) labradorite, (2) labradorite and augite, and (3) labradorite and rhombic pyroxene occur, in addition to the olivine-phenocrysts.

One variety is full of glomeroporphyritic aggregates of olivine, augite, and labradorite (South Mains and Rock Skelly). No

rhombic pyroxene has been found in the lavas from Lunan Bay to the Red Head.

(2) Order of eruption of the different types.—The stratigraphical succession of these varieties of lava appears to be as follows:—

Latest eruptions (Red Head).	Glomeroporphyritic olivine-basalt, less basic than usual.
	(Slight unconformity.)
	Normal type of olivine-basalt, with phenocrysts of olivine only.
	(Slight unconformity.)
	Olivine-basalt, with phenocrysts of basic labradorite, and olivine confined to the ground-mass.
	Normal olivine-basalt. (Base not seen.)
Cairnconnan Series of sandstones.	
	Normal olivine-basalt. (Upper limit not seen.)
	Olivine-basalt, with phenocrysts of olivine, labradorite, and sometimes pyroxene.
	Enstatite-basalt, with phenocrysts of enstatite and basic labradorite.
	Olivine-basalt, with phenocrysts of olivine, labradorite, and pyroxene.
	Olivine-basalt, with phenocrysts of olivine and labradorite.
	Normal olivine-basalt.
	Gap due to a fault.
	Enstatite-basalt.
	Normal olivine-basalt.
	Gap due to a fault.
Earliest eruptions exposed (near Montrose).	Olivine-enstatite-basalt, with phenocrysts of labradorite and enstatite, and olivine in the ground-mass.

(3) Minerals present.—Felspar. The phenocrysts vary in composition from medium to basic labradorite. They are often quite fresh, exhibiting twinning of albite, Carlsbad, and pericline types. In some rocks, however, they are so much altered as to be incapable of determination. The commonest alteration-products are calcite and chlorite.

Glass inclusions are common.

The felspar-crystals of the ground-mass are frequently twinned, and prove to be labradorite of a less basic type than the phenocrysts in the same rock.

A peculiar type of felspar giving rhomboidal sections is found sporadically in many of the olivine-basalts. The crystals are rarely twinned.

Olivine.—No fresh olivine has been found in any of these rocks. The commonest type of pseudomorph has a green serpentinous interior bordered by reddish-brown material, which also traverses the irregular cracks in the crystal. This type passes gradually into a type entirely serpentinous on the one hand, and into a type devoid of green decomposition-products on the other. Crystals of the latter type are sometimes pleochroic and fibrous, resembling iddingsite. The green alteration-product is frequently fibrous, pleochroic, and strongly birefringent. In the more altered rocks it becomes colourless, but still exhibits strong double refraction. When most altered, the olivine is represented by pseudomorphs in rhombohedral carbonates and iron-oxides.

In many of the rocks in which phenocrysts of olivine are present, small crystals also occur in the ground-mass. In some types, the olivine, although one of the first minerals to crystallize, never attains a greater size than that of the other minerals of the ground-mass.

Monoclinic pyroxene.—The augite is pale green to colourless in thin section. The larger crystals are commonly twinned, but the mineral is most abundant in the ground-mass in a granular form, though occurring (rarely) as small prisms.

Rhombohedral carbonates are the usual decomposition-products, though sometimes the augite is replaced by chloritic material.

Rhombic pyroxene.—A very fresh, non-pleochroic, rhombic pyroxene occurs in some of the olivine-basalts near Montrose. It is sometimes intergrown with augite; but, more generally, each crystal of enstatite has a border of granular augite.

Green faintly-pleochroic bastite is the most characteristic alteration-product, but further alteration produces rhombohedral carbonates and even secondary quartz. In the much-altered rocks it is not always possible to distinguish satisfactorily between the rhombic and the monoclinic pyroxenes.

Rhombic pyroxene has not been found as a constituent of the ground-mass of any of the rocks.

A glomeroporphyritic aggregate of bastite, enclosing olivine and basic plagioclase, was found in a section of one of the lavas west of Boddin Point.

Magnetite occurs as well-formed octahedra in the ground-mass of some of the rocks. In the granular form, it is always abundant in the interstitial glass. Hæmatite and limonite are also abundant.

Apatite-needles occur in all the rocks.

Biotite is fairly abundant in a few rocks. It occurs as clear crystals, one giving the characteristic optical figure, and as opaque rods and fibres.

The minerals that fill the amygdaloidal cavities have been described by Heddle.[1] The commonest are calcite, chalcedony, and chloritic minerals (celadonite and saponite).

(4) Structures.—The great majority of the rocks consist of phenocrysts set in a ground-mass of felspar-laths—generally with some augite—and interstitial glass, which is sometimes more abundant than the minute crystals of the ground-mass. The ground-mass is holocrystalline in some of the rocks.

Well-marked flow-structure is usually indicated by the arrangement of the felspar-laths and by the elongation of the amygdaloidal cavities.

Microporphyritic structure is frequently seen, and one rock-type is characterized by an abundance of glomeroporphyritic aggregates. Glomeroporphyritic structure is occasionally met with throughout.

Some very fine-grained rocks occur, in which the phenocrysts are similar in size to the minerals in the ground-mass of the usual type. One example is extensively developed inland at Compass Hill, Friockheim, and Wuddy Law.

(*b*) Dykes.

The only evidence of intrusion among the rocks in this area is furnished by a series of dykes of Lower Old Red Sandstone age north of Lunan Bay. All these rocks are much altered, but appear to be very similar. They may be called porphyrites. The one that is least altered occurs near Fishtown of Usan. Its felspar-phenocrysts are probably andesine, and are full of glass-inclusions and iron-oxides. Some doubtful pseudomorphs which occur may have been pyroxene, but now consist of silica. The ground-mass includes some stout plagioclase-crystals as well as felspar-laths, magnetite, hæmatite, and dusty interstitial glass. Some small patches consist of hæmatite enclosing the felspars poikilitically. The numerous amygdales contain chalcedony, quartz, and chlorite.

The other rocks are finer in texture, but possess similar minerals and structures. In addition, they contain a yellowish-white opaque mineral which is apparently leucoxene after ilmenite. The supposed pyroxenes are few and small in proportion to the felspar, and there is no suggestion of olivine having been present, so that these rocks are much less basic than the lavas.

IV. The Sediments Associated with the Lavas.

(*a*) Petrography of the Sediments.

The sedimentary material varies in colour from pale green, through various shades of grey and brown, to bright red. It is fine-grained, compact, and usually hard, resisting the action of the

[1] 'Mineralogy of Scotland' vol. ii (1901) pp. 138–140, 145, &c.

waves better than the volcanic rock in which it occurs. It breaks most easily along the bedding-planes, the newly-broken surface being covered with mica-flakes. Extremely fine-grained layers alternate with relatively coarser sediment. In the fissures and cavities, the bedding is less horizontal and regular than in the sheets of sediment.

High powers of the microscope are necessary for the determination of the minerals even in the coarser layers, the finest material consisting of fragments too minute to be dealt with in an ordinary rock-section.

The following minerals have been distinguished: quartz, felspar (orthoclase, microcline, and plagioclase twinned on the albite-plan), pale and dark micas, magnetite and red oxides of iron, augite, and chlorite.

In addition, a few small fragments of glassy lava containing minute felspar-laths, have been found in almost every section examined. These fragments are always of the same order in size as the mineral-fragments among which they occur. The fragments are generally angular, but the larger grains tend to be subangular. The relative proportions of the constituents vary much in different specimens, the coarser varieties being richer in quartz, felspar, and larger flakes of mica, and the finer-grained types containing more mica (in minute flakes) and chlorite. The pale-green sediments with abundant chlorite seem to be generally associated with amygdaloidal lavas containing felspar-phenocrysts; but, on the whole, the sediments are very much alike, irrespective of their immediate surroundings. The cementing material is usually calcite, which is frequently in optical continuity over small areas; sometimes it consists of chalcedonic silica.

The material which forms the matrix of the well-rounded boulders of the true conglomerates interbedded with the lavas is very different from that described above, though the difference is perhaps more in degree than in kind. It is reddish or purplish-brown usually, and is much coarser-grained and softer. The fragments are approximately equal in size, some being well rounded, others subangular and angular. The great majority of the fragments consist of felspathic lavas with considerable interstitial glass. The felspars are sometimes quite fresh, showing twinning of the Carlsbad, albite, and pericline types, and giving the extinction of labradorite. The glass is usually crowded with magnetite dust, and is amygdaloidal; but, with the exception of a few pseudomorphs after olivine, no other original minerals could be recognized in it. If we may judge from the imperfect evidence available, the fragments are mainly of basaltic or andesitic lavas. A few rounded grains of quartz and flakes of muscovite also occur. Green chloritic material, in radial aggregates, forms the matrix. Thin beds of sediment similar to this, but without boulders, have been found among and at the surface of the conglomerates, and even among the lavas in a position similar to that of the horizontal sheets of sediment of the more usual fine-grained type.

No satisfactory evidence has been obtained, such as to prove that any of the sedimentary material among the lavas has accumulated as the result of direct ejection from volcanoes. It might simply be the product of the rearrangement in water of rock-waste derived from an adjacent land-area, where gneissose or granitic rocks, or pre-existing sandstones, and volcanic rocks of Lower Old Red Sandstone age, were exposed.

The sandstones and fine conglomerates in the vicinity of the Red Head, south of and above the highest lava in the series, include a considerable quantity of volcanic débris mixed with ordinary sedimentary material. The volcanic fragments are very abundant in certain layers, and absent from others. They are sometimes well rounded; but angular fragments, probably andesitic or basaltic, are always included. Quartz and pale and dark micas form the bulk of the remaining material, but fragments of red sandstone and chlorite-schist also occur.

The cementing material consists chiefly of chalcedonic silica and red iron-oxides.

(*b*) Amygdaloidal Sediments.

(1) The conditions of formation of cavities in the sediments.—From what has been said as to the relations between the lavas and the sediments, it may not be unreasonable to assume that successive streams of molten rock were poured out into water in which fine sediment was constantly accumulating. The persistence of these conditions further suggests a gradual subsidence of the area, which, however, was varied from time to time by stationary conditions—as indicated by the contemporaneous decomposition of some of the lavas; and by actual re-elevation and erosion, of which the interbedded conglomerates and the irregular surfaces upon which these conglomerates rest are unmistakable evidence.

A flow of liquid rock over unconsolidated sediment containing water can hardly take place without important effects being produced upon both the lava and the sediment. The examples of pillow-structure mentioned above indicate how the lavas have been affected by being poured into water, for Tempest Anderson[1] has shown that pillow-structure may be produced in shallow water. Further, the same author[2] has described how the lava boils the water into which it is poured, producing explosions which throw masses of lava into the air. Such conditions will necessarily lead to the accumulation of a layer of clinker-like fragments upon the surface of the lava-stream.

But, beyond examples of the baking of the sedimentary material by molten lava, we have no instance in modern volcanic phenomena yet described that furnishes a parallel to some of the peculiarities which may be observed in Forfarshire.

The mechanical effect of the movement of the molten rock

[1] 'The Volcano of Matavanu in Savaii' Q. J. G. S. vol. lxvi (1910) p. 632.
[2] *Op. cit.* p. 639 & pl. li.

over the moist sediment has been to buckle up, distort and break the superficial layers, the lava sometimes forcing itself into the soft sediment; portions of the sediment were detached from the main mass and carried along in the lower portion of the lava-stream, assuming a roughly spheroidal form. Nodules of this kind embedded in lava have been found, varying from an inch to over a foot in diameter.

The heating effect of the molten rock has been:—

(i) To bake the sediment with which it came into contact, giving rise sometimes to new minerals, especially in the case where spheroidal lumps of sediment have been incorporated by the lava, and consequently subjected to a higher temperature for a longer time.

(ii) To boil the water in the sediment without allowing the steam to escape, thus producing spheroidal cavities within the unconsolidated sediment. The whole of the sediment may be rendered vesicular in this way, or the upper portion only. The cavities appear to have originated in the coarser layers of sediment, where the spaces between the particles were necessarily larger and where, in consequence, a greater amount of water would be stored. The finer layers are frequently bent and broken up in connexion with the provision of more space for these steam-cavities.

Some of the spheroidal masses of sediment included within the lava possess this vesicular structure, as well as the sediment below the lava. The vesicular structure is also commoner in the interbedded sheets of sediment than in the sediment filling up the fissures, though it is not absent from the latter.

The combination of mechanical movement with heating has led to an elongation of the vesicles in the direction of flow, similar to that of the gas-cavities in slaggy lavas. In one example, a mass of sediment 3 feet in diameter and 9 inches thick may be seen to rest upon a sheet of lava, the rock above and around it having been completely removed. From its nether surface wedges of its substance project into crevices in the lava beneath. It is composed of finely stratified, very fine-grained sediment, the outer layers of which are roughly parallel to the external surfaces of the mass; but in the interior the material is crumpled up, and the layers are separated one from the other and sometimes broken across.

The narrowest cavities are filled with chalcedony; larger ones are lined with chalcedony, with quartz in the interior; and in the largest, the order is chalcedony, then quartz, with calcite in the centre. In some cases the chalcedony is succeeded by radial aggregates of needle-shaped green crystals with high double refraction, probably epidote.

It seems clear that, unless the cavities had been filled with gases until the sediment solidified, they could not have continued to exist under the pressure of the superincumbent lava.

A detailed description of an instance of the effect of heat unaccompanied by mechanical movement may not be out of place (Pl. XLV, fig. 4 & Pl. XLVI, fig. 6). The sediment is contained

in a large cavity, 14 inches deep, in compact lava. A vertical section of the cavity and its contents has fortunately been made by wave-action at the foot of the cliff. The plane of the section is such that the cavity appears to be completely enclosed by the lava without any obvious connexion with the surface. The lower part only of the cavity contains sediment; the bedding of the sediment is undisturbed, and the sediment is not altered where in contact with the lava. It seems certain that the cavity was one of the usual steam-cavities[1] in the lava which somehow came into communication with the surface, and so became partly filled with fine sediment.

The lowest part of the cavity contains well-stratified, compact sediment without amygdales. Above this the sediment is full of amygdales, consisting of calcite and chlorite, and the stratification is broken up, portions of the finer-grained layers being set in the solid mass at all angles. The upper part of the cavity is filled with green chloritic material enclosing a large crystal of calcite. Obviously, the breaking up of the sediment was not due to external pressure, because the walls of the cavity are intact and the sediment at the bottom is quite undisturbed. The only explanation that seems at all likely is that the sediment was deposited in water in the cavity, and before this was quite filled another sheet of molten rock flowed over the surface of the already cooled lava in which the cavity occurs. The fresh access of heat boiled the water in the cavity from the surface without being sufficient to penetrate to its base, just as water may be boiled near the top of a test-tube while the lower part is cool enough to be held in the hand. The steam was unable to escape, owing to the sealing-up of the outlet of the cavity by the lava that supplied the heat, and the sediment consolidated with its upper layers full of vesicles which, as well as the empty upper part of the cavity, ultimately became filled with secondary minerals.

Examples of small fissures filled with amygdaloidal sediment in the base of a lava-stream have been observed near the 'Spectacle.' The fissures die out upwards, and it seems impossible for the sediment to have entered from above. I can only conclude that the lava boiled the water in the sediment over which it was poured, and the wet sediment was forced up into the crevices in the nether surface of the lava-stream.

Amygdaloidal cavities have also been occasionally observed in the lower portion of the sediment where it is in contact with the lava beneath. They occur frequently, too, in the sediment that cements the loose blocks at the surfaces of lava-streams. It is possible that some of these instances may be due to the escape of gases from the lava during the accumulation of the sediment.

[1] A similarly-shaped cavity, 1 foot in diameter, in the same lava only a few feet away was lined with chalcedony, inside which was a layer of bipyramidal quartz-crystals with a large hollow in the interior partly filled by crystals of calcite and selenite. This is simply a rather large amygdale, occurring in a cavity which did not communicate with the surface.

(2) The composition of the amygdales in the sediments.—The minerals filling the amygdaloidal cavities in the sediments are practically the same as those found in the lavas. Calcite is perhaps the commonest, and under the microscope can be seen to have grown from the sides of the cavities as little dogtooth crystals, the rest of the interior of the cavity being then one mass of calcite in crystalline continuity. The cavities are often lined, and sometimes filled, with green chloritic material, in fibrous spherulitic aggregates, and sometimes with a green pleochroic and highly doubly-refracting fibrous mineral. Opal, chalcedony, and quartz have also been noted, and the amygdales are occasionally stained red with iron-oxides.

(c) Metamorphism of the Sediments.

The most characteristic secondary mineral produced in the sediments by thermo-metamorphism is brown to golden-yellow in thin section, possesses perfect cleavage, and extinguishes parallel to the cleavage. It is slightly pleochroic and very strongly doubly refracting. It has no definite crystal-outline, only occurring in small, roughly square sections. It most closely resembles astrophyllite. The mineral is present in quantity, roughly parallel to, but away from, the contact-zone in the nodules of sediment enclosed in lava, and also occurs in other sections of baked sediment.

A rude foliation, due to the development of secondary mica in a narrow zone parallel to the surface of contact, occurs in one of the sediments in contact with a basalt. The basalt itself has a thin selvage of tachylyte with a few felspar-microliths.

V. Fault-Breccias.

The most striking example is that of the Rock of St. Skae, which clearly owes its power to resist the elements more to its reinforcement by a multitude of veins of quartz, than to the dyke-rock that apparently forms its core.

The material filling the north-and-south fractures is seen, under the microscope, to consist of ferruginous chalcedonic silica and quartz, with a curious banded effect simulating the flow-structure of rhyolites. The transverse veins are obviously more recent, as they break across the others, in some cases binding together a breccia in which fragments of the older quartz-veins are included. Their silica is entirely cryptocrystalline.

The excessive alteration of the volcanic rocks adjacent to the fault suggests at once a probable source of the silica in the veins.

Other examples may be seen about a quarter of a mile west of Montroseness Lighthouse, east of Mains of Usan, and on the south side of Lunan Bay.

A dyke-like fault-breccia occurs a quarter of a mile west of Boddin Point, in which calcite, as well as silica, is deposited in the vein.

At Dunninald Den, the fault-breccia consists of a broken-up mass of volcanic rock and of the sediment usually found among the lavas, the whole being consolidated by secondary silica.

VI. Conclusions.

The Lower Old Red Sandstone rocks in this area furnish abundant evidence of a long-continued series of volcanic eruptions. The products of the eruptions are lavas which appear to have been poured out in water in which fine sediment was accumulating, the lava being much fissured and the fissures and cavities in it being filled with sediment. Lenticular beds of conglomerate resting upon denuded surfaces of volcanic rocks indicate that the volcanic material occasionally appeared above the water, although the most prevalent conditions were those of subsidence. A rude pillow-structure has been observed in the basal portion of some of the lava-flows. No definite pyroclastic material has been found.

The rocks are almost entirely olivine-basalts, though in a few of them olivine is not present, its place being taken by rhombic pyroxene. It is possible that some of these may be basic andesites, but their felspars are as basic as those of the typical basalts, and their structures also correspond with those of some of the types rich in olivine.

A few dykes of Lower Old Red Sandstone age occur, which are less basic than any of the lavas. They may be termed porphyrites.

Several of the fault-breccias have been cemented with silica derived from the decomposition of the adjoining volcanic rocks, and in consequence are better able to resist the action of the weather, thus producing features outwardly similar to dykes.

The fine sediments associated with the lavas bear evident traces of the pouring over them of molten rock prior to their consolidation. The effects of deformation due to mechanical stress acting on unconsolidated sediments, mineralogical changes, and cavities (probably due to the boiling of water in the sediments or the bubbling of gases through them), the cavities being now occupied by secondary minerals, have all been observed in these sedimentary rocks.

Incidentally, the examination of the coast-sections has revealed the presence, in the south-west of Lunan Bay, of what is probably a mass of Upper Old Red Sandstone resting unconformably upon the lavas of Lower Old Red Sandstone age.

My best thanks are due to Prof. Sir Thomas H. Holland, K.C.I.E., for providing me with every facility for carrying out this piece of work, and for his kind help and advice during its progress. I am also deeply indepted to Dr. G. Hickling, who not only suggested the work to me, and placed at my disposal his own intimate knowledge of the locality, but has also assisted me throughout with friendly advice and criticism.

EXPLANATION OF PLATES XLV & XLVI.

Plate XLV.

[Illustrating the relations between the lavas and the sediments.]

Fig. 1. Cliff-section south of Kirk Loch. The compact lava at the base becomes increasingly fissured, and passes into loose blocks above. All the fissures and the spaces between the blocks are filled with fine sediment. The section shows about 8 feet vertically.

2. Horizontal and vertical section on the shore south of Rock Skelly. A network of sandstone-filled fissures is shown in plan in the foreground. The handle of the hammer rests against a mass of sandstone which is partly horizontal and partly almost vertical.

3. Stack on the shore in Kirk Loch. Vertical height = about 12 feet. Horizontal lenticular beds of sandstone 3 to 6 inches thick among the lava near the base of the section.

4. Cavity in lava partly filled by sediment; at the base of a cliff east of Dunninald Den. The stratification of the sediment in the lower part of the cavity is undisturbed; above, the layers of sediment are broken, and amygdales appear (see Pl. XLVI, fig. 6). At the top of the figure, amygdaloidal sediment may be seen entirely filling another cavity.

Plate XLVI.

[Microphotographs of rocks from the Forfarshire coast.]

Fig. 1. Enstatite-olivine-basalt, near Montroseness. Phenocrysts of labradorite and fresh enstatite. Olivine, labradorite, granular augite, magnetite, and dusty interstitial glass in the ground-mass. The olivine occurs as serpentinous pseudomorphs with borders of hæmatite. ×20.

2. Enstatite-basalt, south-west of Fishtown of Usan. Phenocrysts of basic labradorite and bastite pseudomorphs after rhombic pyroxene in a glassy ground-mass full of magnetite dust, with felspar microlites. Interesting intergrowths of felspar and pyroxene occur. ×20.

3. Olivine-basalt (normal type) on the shore south of Rock Skelly. Pseudomorphs in serpentine and hæmatite after olivine-phenocrysts. The ground-mass shows microporphyritic labradorite, augite, magnetite, and interstitial glass. ×20.

4. Olivine-basalt east of Ethie Haven. Normal type, with holocrystalline ground-mass. Minerals as in fig. 3. ×20.

5. Glomeroporphyritic olivine-basalt, South Mains Quarry, Ethie. The glomeroporphyritic aggregates contain olivine (serpentine and hæmatite pseudomorphs), twinned augite, and labradorite. Felspar, granular augite, iron-oxides, and a little interstitial glass occur in the ground-mass, which indicates flow-structure. This type is on the whole less basic than usual. ×20.

6. Amygdaloidal sandstone from a cavity in lava east of Dunninald Den (Pl. XLV, fig. 4). The finer layers of sediment appear to have broken up while the coarser sediment was still unconsolidated. The amygdales contain chlorite and calcite. ×6.

Discussion.

Dr. J. W. Evans remarked on the interest of the paper and on the clearness with which the Author had placed the facts and his conclusions from them before the Society. It was remarkable that the Lower Old Red Sandstone lavas of this area should be so much more basic than those of the Cheviots. The speaker was still inclined to believe that many of the conglomerates were due to

1.

2.

3.

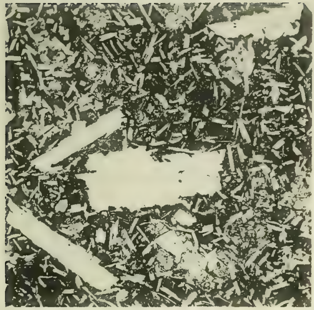
4.

A. J. Photo.

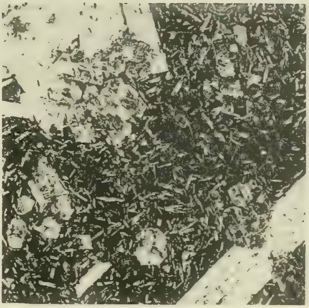
Bemrose, Collo. Derby.

LAVAS AND SANDSTONES OF THE FORFARSHIRE COAST.

1. ×20



2. ×20



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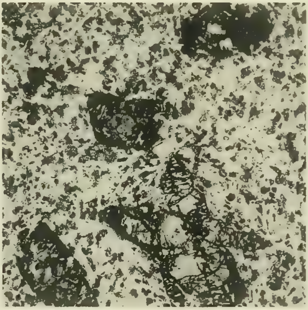
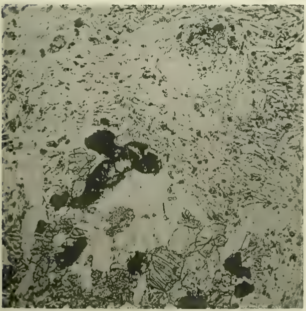
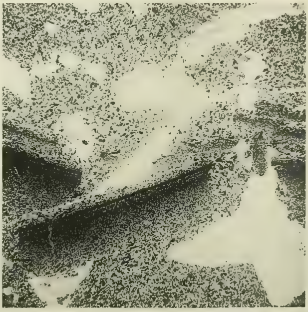
4. ×20



5. ×20



6. ×6



A. J. Photo. Bemrose, Collo, Derby.

MICROPHOTOGRAPHS OF ROCKS FROM THE FORFARSHIRE COAST.

torrent-action. How did the Author explain the occurrence of the sedimentary material in the interstices of the lava? Was it washed in by the water of a lake, or by rain-water, or was it the result of æolian action? The suggestion that cavities were formed by steam in sedimentary rocks below a lava-flow was very valuable.

Dr. J. V. Elsden remarked on the petrographical interest of the paper. Some of the rock-types appeared to be rich in magnesia, and the augites might be expected to show the basal striation characteristic of such rocks in other areas. He asked whether these various rock-types occurred in separate lava-flows, or in different parts of the same flow. The character of the phenocrysts suggested an origin from a differentiated magma-basin. It would be interesting to know what kind of rocks marked the dyke-phase of these eruptions.

The Author thanked the Fellows for their kind reception of his paper. In reply to Dr. Evans, he said that true conglomerates, indicating the action of strong currents, are occasionally interbedded with the lavas. The fragments of slaggy lava cemented by fine sediment are found at the surface of almost every lava-flow, and were probably produced simultaneously with the lava below. He stated, in reply to Dr. Elsden, that each of the types of volcanic rock mentioned generally includes several sheets of lava. None of the augite-crystals show basal striation. The few dykes consist of much-weathered rock, less basic than the lavas, no olivine and very little pyroxene being present.

22. *The* Bathonian Rocks *of the* Oxford District.

By M. Odling, M.A., B.Sc., F.G.S. (Read May 7th, 1913.)

[Plates XLVII & XLVIII.]

Contents.

I. Introduction.

This work was undertaken at the suggestion of Prof. Sollas, who supervised the work, and at his suggestion a large number of rock-sections have been examined.

To Mr. W. W. Fisher, M.A., Public Analyst for Oxfordshire, Berkshire, & Buckinghamshire, I am indebted for much help and many valuable suggestions in carrying out the chemical analyses. I must also express my thanks to Mr. Linsdall Richardson for kindly verifying a number of my identifications, and for his help in the correlation of the beds with those of other districts.

My thanks are also due to Mr. R. C. Sikes, M.Inst.C.E., for permission to visit the Ardley Cutting, and to the Directors of the Oxford Portland-Cement Works, who, contrary to their regulations, readily granted me permission to examine their quarry.

II. General Description.

The rocks described in this paper form a well-defined series sharply separated from the underlying beds, consisting of the *Clypeus* Grits on the west and Northampton Sands on the east; and from the Oxford Clay, which nearly always conformably succeeds.[1]

Throughout the series there is a general westward thickening, especially marked in the lower members of the Great Oolite.

[1] In the Calvert boring, the whole of the Cornbrash is missing; see A. M. Davies & J. Pringle, Q. J. G. S. vol. lxix (1913) p. 333. The description of the strata in that boring suggests to my mind the absence also of the lowest beds of the Oxford Clay of the district—the beds that probably represent the Kellaways Clay.

The Cornbrash.

This consists of rubbly non-oolitic limestones of various degrees of coarseness containing the normal Cornbrash fauna. The total thickness appears to be only about 17 feet,[1] of which the upper part is characterized by *Microthyris lagenalis*, the lower by *Terebratula intermedia*. Cephalopods are far from abundant, there being apparently but two records: namely, *Clydoniceras discus* from Kirtlington[2] and *Macrocephalites macrocephalus* from Witney[3]

The Forest Marble.

This formation alters considerably when traced from west to east. On the west it consists for the most part of compact shelly and oolitic limestones, with only minor bands of clay or marl; in the centre of the district the false-bedded limestones are broken up into groups by numerous bands of horizontally-bedded marl or clay; while on the east clays and marls predominate, and the limestones on the whole are but slightly oolitic and very marly.

The thickness in the area under consideration is only from 21 to 28 feet, while at Alderton, south-west of Malmesbury, the thickness is about 60 feet.[4]

The incoming of the Forest Marble is represented by a well-marked eroded surface at the top of the Great Oolite, which is often much ripple-marked and bored and locally covered with oysters; the lower beds of the Forest Marble also contain fragments of the underlying beds.

The Great Oolite.

Except for the uppermost part, which approaches the Forest Marble in lithological character (so much so that in 1860 Prof. Phillips included the top of the Great Oolite in the Forest Marble[5]; this he corrected in his 'Geology of Oxford,' in 1871), the Great Oolite contrasts remarkably with the overlying Forest Marble, in that the series is almost entirely calcareous, false bedding is absent, and the rocks are as a whole much finer in texture. The eastward thinning of the Great Oolite is very remarkable: although there are certain beds which are easily recognizable in all the sections, the intervening beds are found to vary considerably, both in thickness and in lithological character, and it seems probable that some of them actually die out by a series of overlaps before reaching the east of the district.

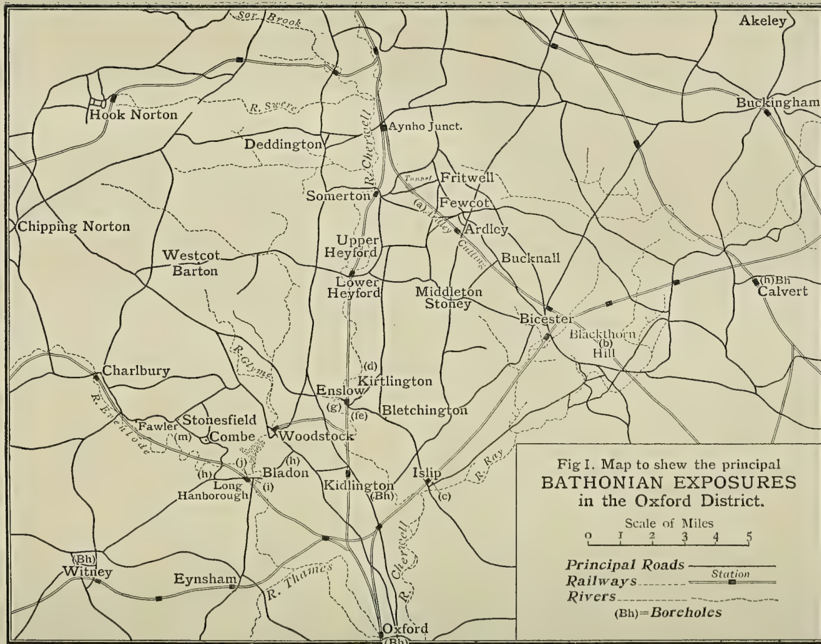
[1] H. B. Woodward, 'Geology of the Country round Oxford' Mem. Geol. Surv. 1908, p. 4.

[2] J. Phillips, 'Geology of Oxford & the Valley of the Thames' 1871, p. 243.

[3] H. B. Woodward, 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iv (1894) p. 446.

[4] S. H. Reynolds & A. Vaughan, Q. J. G. S. vol. lviii (1902) p. 748.

[5] J. Phillips, Q. J. G. S. vol. xvi (1860) p. 118.



[The *h* above the words 'Long Hanborough' should be *k*; the *h* above 'Calvert' should be *n*.]

Mr. Barrow has divided the Great Oolite of the Ardley section into three divisions—designated respectively 1st, 2nd, and 3rd Blocks, taken in descending order[1]; the lower part of the 3rd Block, however, I am inclined to separate off as being Fullonian. Mr. Barrow's divisions are adopted in this paper, with the exception that the break between Block 1 and Block 2 proves to be situated at the base of the First *Terebratula* Bed instead of at the top of it.

Fullonian.

In this district the Fullonian rocks are now recognizable only in the Ardley section, but they have been described in some detail by Mr. A. E. Walford from the Stonesfield and Chipping-Norton districts[2]; and also by Mr. L. Richardson from the latter district.[3]

The upper beds consist of compact, very fossiliferous limestones; while the lower part is almost entirely composed of clays and sandy beds, often of a remarkably green colour. The lowest bed, the 'Chipping-Norton Limestone,' consists of a very argillaceous, somewhat sandy limestone, which in the Ardley Section is crowded with *Rhynchonellæ*, while on the east it consists chiefly of buff-coloured limestone.

The following beds are valuable for purposes of correlation:—

Cornbrash.

Terebratula-intermedia Beds.

Forest Marble.

Great Oolite.

Cream-Cheese Bed, passing down into the Fossiliferous Cream-Cheese Bed.

First *Terebratula* Bed.

Second *Terebratula* Bed.

Nerinæa Rock.

Roach Bed.

Fullonian.

Fuller's-Earth Rock.

Rhynchonella and *Inoceramus* Beds.

Astarte Limestone

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[1] 'Summary of Progress of the Geological Survey for 1907' Mem. Geol. Surv. 1908, pp. 149–50; & Proc. Geol. Assoc. vol. xxi (1909–10) pp. 40 *et seqq.*

[2] 'On some New Oolitic Rocks in North Oxfordshire' Buckingham, 1906; also Rep. Brit. Assoc. 1894 (Oxford) p. 304, *ibid.* 1895 (Ipswich) p. 414, & *ibid.* 1896 (Liverpool) p. 356.

[3] 'Inferior Oolite & Contiguous Deposits of the Chipping-Norton District' Proc. Cotteswold Nat. F. Club, vol. xvii, pt. 2 (1911) pp. 195 *et seqq.*

III. Details of Sections.

(*a*)[1] Ardley Section (fig. 2).

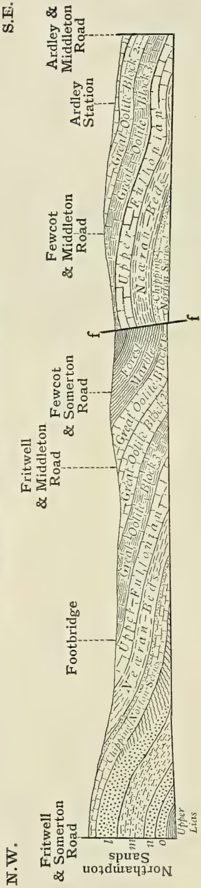

Fig. 2.—*Section from Ardley to Fritwell Tunnel, G.W.R. (new Birmingham main line) on the scale of about $2\frac{1}{2}$ inches to the mile.*

A very complete section was afforded by the cutting on the Great Western Railway (new Birmingham main line) between Bucknall Bridge and Fritwell Tunnel. In a distance of about $3\frac{1}{2}$ miles all the beds were exposed, from the base of the Cornbrash to the top of the Upper Lias.

The beds may be described as undulating, with a general south-easterly dip; about two-thirds of the way between the Fewcot & Somerton Road and the Fewcot & Middleton Road, a reversed fault with a north-westerly downthrow brings the uppermost beds of the Forest Marble against the basal beds of the Great Oolite. The cutting, therefore, virtually affords two sections.

South-east of the fault, all the beds are exposed, from the base of the Forest Marble to near the base of the Chipping-Norton Limestone Series; while, north-west of the fault, the beds from the base of the Cornbrash to the top of the Upper Lias are exposed. The complete section thus afforded is as follows:—

Cornbrash (as a subsoil in the fields near the fault).

	Thickness in feet	inches.
Forest Marble.		
Blue clay	2	9
False-bedded limestones	5	6
Blue clay	1	3
Flaggy limestones	0	9
Dark-blue and green clay	8	0

[1] Letters prefixed to headings of sections refer to the map (fig. 1) p. 486.

GREAT OOLITE.

	Bed	Description	Thickness in feet	inches.
Block 1.	Bed 1.	Cream-Cheese Bed (often largely removed by erosion prior to the deposition of the Forest Marble). This consists almost entirely of amorphous carbonate of lime, without shell-fragments or oolitic grains	0 to 2	0
	Bed 2.	Fossiliferous Cream-Cheese Bed. This bed merges into the above, but is distinguished from it by the presence of numerous shell-fragments; the following fossils occur:—*Nerinæa eudesii* Mor. & Lyc., *Modiola imbricata* Sow., *Pinna cancellata* Bean, and *Terebratula* sp.	4	0
	Bed 3.	Compact fine-grained limestone, with occasional ooliths	3	0
	Bed 4.	Yellow marl; fragments of *Echinobrissus* sp. common	0	4
	Bed 5.	First *Terebratula* Bed: a marly limestone crowded with *T. (Epithyris) bathonica* S. Buck.	0	6

Well-marked eroded surface.

	Bed	Description	Thickness in feet	inches.
Block 2.	Bed 6.	Compact white limestone, with occasional ooliths.	1	9
	Bed 7.	Second *Terebratula* Bed: a marly, friable, fossiliferous limestone, yielding *T. (Epithyris) bathonica* S. Buck., *Modiola imbricata* Sow., *Lima cardiiformis* Sow., *Plagiostoma (?) punctatum* (Sow.), *Echinobrissus woodwardi* Wright, and *Trigonia* sp.		
	Bed 8.	Creamy white limestone, with a few *Nerinæa*	1	0
	Bed 9.	*Nerinæa* Rock, a compact limestone almost entirely composed of specimens of *Nerinæa* aff. *funiculus* Desl., in a marly matrix	1	0
	Bed 10.	Soft marly limestone, with fragments of *Pholadomya*, *Modiola*, and *Nerinæa*	1	0
	Bed 11.	Freestone. This is the highest bed from which *Clypeus mulleri* Wright has been obtained; *Nautilus subtruncatus* Mor. & Lyc. also occurs...	1	0
	Bed 12.	Marly parting, very persistent throughout the cutting	0	1
	Beds 13 to 20.	Eight beds of compact limestone, with few fossils	8	0
	Bed 21.	Roach Bed. This bed has been described by Mr. Barrow as follows[1]:—'A somewhat siliceous limestone from which the fossils are dissolved out . . . leaving a curiously porous-looking rock.' The bed is highly fossiliferous, but the fossils occur mostly as casts, and are ill-preserved; the following have been identified:—*Nerinæa* aff. *funiculus* Desl., *Cyprina* sp., *Corbicella bathonica* Mor. & Lyc., *Lima cardiiformis* Sow., *Grammatodon hirsonensis* (d'Arch.), *Modiola imbricata* Sow., *Pleuromya goldfussi* Lyc., and *Trigonia* sp.	0	6 to 8

[1] Proc. Geol. Assoc. vol. xxi (1909–10) p. 42; & 'Summary of Progress of the Geological Survey for 1907' Mem. Geol. Surv. 1908, p. 150.

			Thickness in feet	inches.
Block 3.	Bed 22.	Blue clay, quickly weathering brown	1	0
	Bed 23.	Sandy argillaceous limestone, finely laminated, yielding *Terebratula* sp., *Ostrea sowerbyi* Lyc., *Cypricardia rostrata* Sow., and radioles of echinoderms	1	6
	Beds 24 & 25.	Argillaceous limestone in two beds, the lower one being rather sandy	2	9
	Bed 26.	Hard grey limestone, largely composed of shell-fragments, containing *Terebratula* sp., *Modiola imbricata* Sow., *Ostrea sowerbyi* Lyc., and *Lima cardiiformis* Sow.	1	9
	Bed 27.	Grey, laminated, sandy limestone, with a few specimens of *Ostrea sowerbyi* Lyc.	0	6

FULLONIAN.

Upper Fullonian.	Bed 28.	Compact yellow limestone, sometimes grey, yielding *Rhynchonella varians* Schloth., *Rh.* sp., *Terebratula* cf. *globata* Sow., *Ceromya concentrica* Sow., *Cypricardia rostrata* Sow., *C. bathonica* d'Orb., *Homomya vezelayi* Mor. & Lyc., *Lima cardiiformis* Sow., *Modiola imbricata* Sow., *Pholadomya deltoidea* Sow., *Ph. heraulti* Ag., and *Pleuromya* cf. *scarburgensis* Mor. & Lyc. ...	1	6
	Beds 29 & 30.	Sandy clay; upper part blue, lower part brown...	2	9
	Bed 31.	Fuller's-Earth Rock: a compact non-oolitic limestone with three clay-partings; it yields *Teloceras subcontractum* Mor. & Lyc., *Natica pyramidata* Mor. & Lyc., *Ceromya concentrica* Sow., *Cypricardia rostrata* Sow., *C. bathonica* d'Orb., *Gresslya peregrina* Phil., *Lima cardiiformis* Sow., *Lucina bellona* d'Orb., *Modiola imbricata* Sow., *Ostrea sowerbyi* Lyc., *Pholadomya heraulti* Ag., *Ph. deltoidea* Sow., *Pleuromya* cf. *sinistra* Ag., *Terebratula globata* Sow., *Rhynchonella concinna* auctt., *Rh. varians* Schloth., and *Clypeus mulleri* Wright	4	0
	Bed 32.	Local sandy parting	0	2
	Beds 33, 34, & 35.	*Rhynchonella* and *Inoceramus* Beds: blue argillaceous limestones and clays, locally divisible into three. They yield *Actæonina gigantea* Mor. & Lyc., *Natica pyramidata* Mor. & Lyc., *N. globosa* Rœm., *Camptonectes lens* (Sow.), *Ceromya concentrica* Sow., *Gervillia* aff. *ovata* Sow., *Inoceramus obliquus* Lyc., *Lima cardiiformis* Sow., *Modiola imbricata* Sow., *Ostrea sowerbyi* Lyc., *Pecten* sp., *Pholadomya heraulti* Ag., *Rhynchonella concinna* auctt., *Terebratula globata* Sow., *Acrosalenia wiltonii* Wright, *Clypeus mulleri* Wright, *Cl. ploti* Wright, *Echinobrissus* sp., and *Isastræa limitata* Lamx.	4	6

Unconformity, especially well shown on the site of the northern end of Ardley Railway-Station, where Beds *a* & *b* of the Neæran Beds are absent; this unconformity marks the position of the Stonesfield Slates at Stonesfield.

		Thickness in feet	inches.
Lower Fullonian.	Neæran Beds: these consist for the most part of rapid alternations of greenish and blackish sands and clays; the lithological character of the different beds varies considerably within a very short distance; only the following general section can, therefore, be given ....about	18	0
	(*a*) Compact green clay, with much wood......	0 to 3	3
	(*b*) Green clay, yielding many specimens of *Cardium incertum* Phil......................	0 to 1	0
	(*c*) Laminated dark and light clay, locally almost black..................................	1	6
	(*d*) Grey and green sands, locally replaced by a sandy limestone with rootlets	1 to 3	0
	(*e*) *Astarte* Limestone: a pale greyish-green sandy limestone, crowded with specimens of *Astarte angulata* Mor. & Lyc., and often containing rootlets	1 to 1	6
	(*f*) Dark-green clays yielding *Cardium incertum* Phil., *C. stricklandi* Mor. & Lyc., and *Astarte angulata* Mor. & Lyc.	1	3
	(*g*) Dark-green clays; unfossiliferous, except at the extreme base, where there is a band of *Ostrea sowerbyi* Lyc................	0	6
	(*h*) Grey clays and sand, becoming darker at the base	3	6
	(*i*) Green clay	2	0
	Chipping-Norton Limestone Series, consisting of:—		
	(*j*) Grey calcareous sandy clay, yielding *Pinna cancellata* Bean, *Modiola imbricata* Sow., and *Nautilus* sp.	2	6
	(*k*) Bird's-Nest Rock: a hard, sandy, argillaceous limestone with numerous black specks,[1] which quickly weathers to a sandy clay containing *Hemicidaris bravenderi* Wright, *Rhynchonella* sp., *Pinna cancellata* Bean, *Ostrea sowerbyi* Lyc., *Modiola imbricata* Sow., and *Zigzagiceras wagneri* (Oppel),[2] as also numerous curious tube-like segregations of coarse material, the possible origin of which is discussed on a later page (see p. 503).	8	6
Northampton Sands.	Bed *l*. False-bedded limestones, which pass laterally into a pale lilac clay, when traced towards the tunnel (? Chipping-Norton Limestone)	12 to 15	0
	Bed *m*. Black sand and clay	15	6
	Bed *n*. Greyish-black sandstone	8	0
	Bed *o*. Compact dark sandstone	10	0
	Upper Liassic Clay (at the tunnel-mouth).		

[1] [Mr. L. Richardson has noted black specks in the Chipping-Norton Limestone of Pointed-Heath Quarry near Chipping Norton; see 'The Inferior Oolite & Contiguous Deposits of the Chipping-Norton District' Proc. Cottesw. Nat. F. Club, vol. xvii, pt. 2 (1911) p. 229.]

[2] Mr. S. S. Buckman considers that the specimen is probably an old-age mutation.

(*b*) Blackthorn Hill, south-east of Bicester.

This section is largely based on the evidence obtained by the officers of H.M. Geological Survey, and by the Geologists' Association, since the exposure was earthed up before this investigation had been begun. There was a clay-pit near here, which has been described by A. H. Green.[1] I had, however, previously visited the section in company with Prof. Sollas in May 1908, while the excavation was in progress.

The Cornbrash is very thin, being only 5 feet 3 inches thick, and is covered by what may possibly be the Kellaways.[2] In the cutting the following section is recorded by the Survey[3]:—

		Thickness in feet	inches.
CORNBRASH.	(Lower part only. Rubbly, shelly, non-oolitic limestone)	5	0
FOREST MARBLE.	Sandy clay, with one pale marl-band	3	6
	Hard, grey, oolitic limestone	1	6
	Dark tenacious clay, passing down to lighter clay, with three pale marl-bands	7	0
	Pale-grey blotchy limestone	3	6
	Pale clay-parting	0	6
	Hard clay-limestone	1	9
	Pale-grey clay	0	6
	Bright bluish-green clay, passing down into grey clay with (?) phosphatic nodules	3	6

At the time of my visit, only the lower beds of the Cornbrash were exposed. They yielded the following fossils:—

Pseudomonotis echinata (Sow.).
Pleuromya securiformis Phil.
Terebratula intermedia Sow.
Pholadomya deltoidea Sow.
Pecten vagans Sow.
Ornithella obovata (Sow.).

Near the top of the Forest Marble a greyish marly band contains numerous specimens of *Gervillia* cf. *waltoni* Lyc. The basal bed evidently corresponds with the basal clay in the Ardley section; while the Forest Marble is, as a whole, more calcareous, and contains more wood than in that section. At Blackthorn Hill the whole of Block 1 of the Great Oolite was exposed, and about 18 inches of Block 2, the sequence being the same as in the Ardley section.

(*c*) Islip Sections.

One quarry, now no longer worked and much overgrown, is seen on the right-hand side of the road leading from the village to the mill. The section shows about 4 feet of Cornbrash resting upon the Forest Marble, which consists of about 4 to 6 feet of clay overlying false-bedded rock: the lower 6 to 8 feet is hidden by talus, and so overgrown that the thickness of the rock cannot be ascertained. A band of clay occurs at the very base of the quarry,

[1] 'Geology of the Country round Banbury, &c.' Mem. Geol. Surv. 1864, pp. 36–37.

[2] H. B. Woodward, 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iv (1894) p. 449.

[3] G. Barrow, Proc. Geol. Assoc. vol. xxi (1909–10) p. 37; and 'Summary of Progress of the Geological Survey for 1907' Mem. Geol. Surv. 1908, p. 145.

as is shown by the fact that water is always held up in ponds. Near this, in the railway-cutting the following section occurs[1]:—

	Thickness in feet.
Cornbrash, yielding *Pseudomonotis echinata* (Sow.), *Homomya gibbosa* Sow., *Gresslya peregrina* Phil., *Modiola imbricata* Sow., *Pecten vagans* Sow., *Pholadomya deltoidea* Sow., *Pleuromya securiformis* Phil., *Terebratula intermedia* Sow., *Ornithella obovata* (Sow.), and *Pygurus michelini* Cott. .... about	3
Clay	8
Hard, grey, oolitic limestone / Flaggy brown oolite } Forest Marble	4
Clay	$2\frac{1}{2}$
White limestone containing *Nerinæa* (Great Oolite).	

It is unfortunate that all the other exposures round Islip are now filled in: since, judging from the list given by Phillips, who mentions no less than sixty-five species from Islip, the exposures have been very fossiliferous.[2]

(*d*) Oxford Portland-Cement Works, Kirtlington.

The Cornbrash here forms a subsoil about 4 feet thick; it is of the usual character, yields the usual fossils (see p. 501), and calls for no special note.

The Forest Marble is only 17 feet thick, and is separated from the Cornbrash by a 2-inch band of clay; the following is the generalized section:—

	Thickness in feet	*inches.*
Bed *a*. Marly clay	0	2
Bed *b*. Horizontally-bedded compact marl	1	9
Bed *c*. Marly clay	1	0
Bed *d*. False-bedded limestone	4	6
Bed *e*. Marly clay	3	0
Bed *f*. False-bedded limestone	2	6
Bed *g*. Marl with limestone-nodules and 'race'	1	9
Bed *h*. Compact marly limestone	1	0
Bed *i*. Compact oolitic limestone	0	6
Bed *j*. False-bedded limestone	1	0
	17	2

Very few fossils occur, and, except for the bottom 18 inches, the limestones are all of a marly character.

Great Oolite.		*Thickness in feet*	*inches.*
Block 1.	Bed 1. 'Fossiliferous Cream-Cheese Bed' (locally becoming oolitic and containing corals)	2	10
	Bed 2. Green clay (brown at the base, where it contains lignite)	3	0
	Bed 3. Shelly limestone	1	4
	Bed 4. Green clay	2	8
	Bed 5. Coarse, brown, marly limestone	0	8
	Bed 6. Green clay	0	4
	Bed 7. 'First *Terebratula* Bed'	1	0

[1] A. H. Green, 'Geology of the Country round Banbury, &c.' Mem. Geol. Surv. 1864, p. 35.

[2] 'Geology of Oxford, &c.' 1871, pp. 239 *et seqq.*

	Beds		Thickness in feet	inches.
Block 2.	8–13.	Oolitic and compact limestones	8	0
	Bed 14.	'Second *Terebratula* Bed'	2	3
	Beds 15 & 16.	Marly limestone (more compact towards the base)	3	0
	Bed 17.	Limestone (the lower part being the '*Nerinæa* Rock')	1	6
	Beds 18–20.	Marly oolitic limestone (full thickness unknown).	4	6

Base of quarry.

Geographically, this exposure occupies a position intermediate between the Ardley section and the Enslow-Bridge sections. One would consequently expect the thicknesses also to be intermediate: on comparing the thicknesses, however, with those in the Enslow-Bridge sections, we find that they are approximately identical; the decrease in thickness appears, therefore, to occur between this section and the Ardley section.

Enslow-Bridge Sections.

There are three quarries at Enslow Bridge: the Upper Green-Hill Quarry, the Lower Green-Hill Quarry, and the Gibraltar Quarry.

Green-Hill Quarries.[1]

Two quarries are opened on the side of the hill, near Bletchington Railway-Station, the upper of which exhibits the base of the Cornbrash and the top of the Forest Marble; the lower exhibits the base of the Forest Marble and the Great Oolite. Fortunately, the upper exposure is sufficiently deep to allow of the lowest beds being correlated with the upper beds of the lower quarry.

The western end of the upper quarry is sufficiently close to the lower quarry to allow of one complete section being shown in the correlation-table.

(*e*) Upper Quarry (Pl. XLVII, fig. 1).

The Cornbrash is exposed to a depth of about 8 feet—which appears to be almost its full thickness[2]; the rock is very fossiliferous, and of the usual character. The lower part consists of a bed of compact limestone, about 2 feet thick at the western end of the quarry, and only a foot thick at the eastern end, where there is a layer of rolled, concretionary, calcareous nodules at the base. The following fossils are especially abundant in this exposure:—*Homomya gibbosa* Sow. (very large specimens, measuring over 6 inches in length), *Pholadomya deltoidea* Sow., and *Pseudomonotis echinata* (Sow.).

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[1] The upper quarry is figured in Proc. Geol. Assoc. vol. xxii (1911) pl. i, fig. 2; the base of the Cornbrash has, however, been drawn too high.

[2] J. Phillips, Q. J. G. S. vol. xvi (1860) p. 117.

In the Forest Marble the beds vary considerably, both in thickness and in character, when traced from one end of the quarry to the other: this may be, in reality, due to false bedding, which would be almost obscured if the direction of the currents were at right angles to the general trend of the section. The section is as follows:—

Western end.	Thickness in feet.	Eastern end.	Thickness in feet.
Bed *a*. Sandy marl	$1\frac{1}{2}$	Bed *a*. Sandy marl	$3\frac{1}{2}$
Bed *b*. False-bedded white oolite	8	Bed *b*. False-bedded white oolite; Bed b^1. Marl; Bed b^2. False-bedded white oolite	8
Bed c^1. Flaggy marl	2	Bed *c*. Flaggy marl	$0\frac{1}{2}$
Bed c^2. Marl	$0\frac{1}{2}$		
Bed d^1., d^2., d^3. False-bedded limestones and clay	1 (seen)	Bed *d*. False-bedded limestones and clay	1 (seen)
Totals	13		13[1]

(*f*) Lower Quarry (Pl. XLVII, fig. 2).

		Thickness in feet	inches.
Bed *b*.	Subsoil of false-bedded limestones about	2	0
Bed *c*.	Flaggy marl	2	0
Bed *d*.	False-bedded limestones and clays	7	6
Bed *e*.	False-bedded limestones, sometimes replaced by Stiff clay (with a very irregular base)	1	9
	Thickness seen = about	12	3

GREAT OOLITE.

Block 1.	Bed 1.	'Fossiliferous Cream Cheese' from 0 to (with a very irregular waterworn upper surface).	1	9
	Bed 2.	Dark-green clay, with much wood (specimens measuring 9 inches in diameter have been obtained)...	3	0
	Bed 3.	Brown sandy bed, with plant-remains	0	8
	Bed 4.	'First *Terebratula* Bed,' as in Gibraltar Quarry	1	0

[1] [Since the above was written, the quarry has been greatly deepened about the centre, and a pit has been sunk, with the object of draining off the water. The following addition to the section was noted (September 1913):—

Bed *d*. False-bedded limestones and clays .... about 8 feet.
Bed *e*. Irregular oolitic marl and limestone, slightly false-bedded. 9 to 15 inches
giving a total thickness for the Forest Marble of 21 feet 3 inches.

The Great Oolite section is as follows:—

Blue-hearted limestone (=Fossiliferous Cream-Cheese Bed)... 2 feet 2 inches.
Dark bluish-green clay .... 4 feet.
Brown marly band with plant-remains .... about 1 foot.

The section was carried down about 11 feet below this, the sequence being similar to that exposed in the Lower Green-Hill Quarry.]

			Thickness in feet	inches.
Block 2	Beds 5–10.	Compact white limestones, with local marl-partings	10	0
	Bed 11.	'Second *Terebratula* Bed,' as in Gibraltar Quarry ...	2	0
	Beds 12–15.	Compact limestones	2	9
	Bed 16.	Brown limestone, passing down into '*Nerinæa* Rock'	2	6
	Bed 17.	Laminated marl	0	6
	Bed 18.	Limestone, yielding numerous teeth and part of a lower jaw of *Teleosaurus brevidens* Phil.; also teeth of *Strophodus* and *Pycnodus*	1	9
	Beds 19–20.	Sandy limestones, with marl above	2	6
		Base of quarry.		

The green clay, Bed 2 in Block 1, is of especial interest, since it is from this bed that the remains of *Cetiosaurus oxoniensis* Phil. were obtained; as this bed underlies the 'Fossiliferous Cream Cheese,' the specimens must have been obtained from the Great Oolite, not from the Forest Marble.

The beds down to the top of the 'First *Terebratula* Bed' were originally included in the Forest Marble by Phillips,[1] but afterwards included in the Great Oolite in his 'Geology of Oxford, &c.'

(*g*) Gibraltar Quarry[2] (fig. 3, p. 497).

A very complete section is afforded in this exposure; but, as the face of the quarry is almost vertical, a detailed collection from some of the beds proved to be impossible. The details of the eroded surface of the Great Oolite were originally more easily observable in this section than in any of the others, since the Forest Marble was quarried back much farther than the Great Oolite, thus leaving a large platform. Unfortunately, quarrying operations have now been carried down into the Great Oolite. The section in Gibraltar Quarry is as follows:—

		Thickness in feet	inches.
Subsoil of rubbly Cornbrash, with the usual fossils		1 to 2	0
FOREST MARBLE.			
Bed *a*.	False-bedded, coarse, oolitic limestones	3	6
Bed *b*.	Horizontally-bedded clay	1	3
Bed *c*.	False-bedded limestones and clays	1	6
Bed *d*.	Horizontally-bedded marly limestones	1	6
Bed *e*.	Compact limestone, false bedding shown on weathering ...	2	0
Bed *f*.	Horizontally-bedded marly oolite	1	0
Bed *g*.	Compact limestone, false bedding only apparent on weathering	2	0
Bed *h*.	Horizontally laminated marl	0	10
Bed *i*.	False-bedded limestones and clays	7	6
Beds *j*, *k*, *l*, *m*, & *n*.	Horizontally-bedded alternations of limestones and marls in five bands	0	8
	Well-marked eroded surface with *Ostrea*.		

[1] Q. J. G. S. vol. xvi (1860) p. 118.

[2] This section has been described by C. J. Bayzand, Proc. Geol. Assoc. vol. xxi (1911) pp. 3 & 4, also pl. ii. Unfortunately, the divisions marked alongside the photograph are incorrect, and most of the fossils recorded from the Forest Marble on p. 3 (*op cit.*) come from Bed 5 of the Great Oolite.

Fig. 3.—*Upper part of Gibraltar Quarry.*

Cornbrash.

Forest Marble.

Fossiliferous Cream-Cheese Bed (top of the Great Oolite).

M. O. photo.

Great Oolite.

Block 1.		*Thickness in feet*	*inches.*
Bed 1.	Fossiliferous Cream-Cheese Bed, passing into an oolitic limestone at the northern end of the quarry. The following fossils have been obtained from this bed:—*Terebratula (Epithyris) bathonica* S. Buck., *Nerinæa eudesii* Mor. & Lyc., and *Modiola imbricata* Sow. ...	2	0
Beds 2–4.	Compact pure limestone, with a band of clay above and below ...	1	5
Beds 5 & 6.	Marly fine-grained limestone, more marly at the base, and yielding numerous fossils: such as *Astarte angulata* Mor. & Lyc., *Cardium buckmani* Mor. & Lyc., *Gervillia waltoni* Lyc., *Modiola imbricata* Sow., *Amberleya nodosa* J. Buck., and *Nerinæa eudesii* Mor. & Lyc. ...	0	9
Beds 7 & 8.	Bluish-green clay, passing into a laminated brown clay ...	1	2
Bed 9.	First *Terebratula* Bed: a marly bed crowded with *T. (Epithyris) bathonica* S. Buck. The bryozoa *Berenicea diluviana* Lamx., and *B. archiaci* Haime[1] are often found encrusting the *Terebratulæ*. This bed rests upon the eroded surface of Block 2, upon which there is often a band of oysters, as also *Isastræa limitata* Lamx. and *Thamnastræa lyelli* E. & H. ...	0	9

[1] See Proc. Geol. Assoc. vol. xxii (1911) pl. iii.

Block 2.		Thickness in feet	inches.
	Beds 10–12. Compact limestone with few fossils	7	3
	Bed 13. Second *Terebratula* Bed: a marly limestone yielding *T. (Epithyris) bathonica* S. Buck., *Cyprina islipensis* Lyc., *Gresslya peregrina* Phil., *Lima cardiiformis* Sow., *Modiola imbricata* Sow., *Ostrea* cf. *sowerbyi* Lyc., *Trigonia* sp., and *Hybodus dorsalis* Phil.	1	3
	Beds 14–23. Chiefly compact limestones, with a few specimens of *Nerinæa* towards the base	8	6
	Bed 24. *Nerinæa* Rock, similar to that which is exposed in the Ardley section	1	9
	Beds 25–27. Compact limestones	3	0

Base of quarry.

(*h*) Bladon Quarry, near Woodstock.

This section exposes the Forest Marble, capped by a rubbly subsoil of Cornbrash, in which fossils are not so numerous as in most of the other exposures; this subsoil is from 1 to 4 feet thick. The section of the Forest Marble is as follows:—

		Thickness in feet.
Bed *a*.	Somewhat marly, false-bedded, oolitic limestones	2½
Bed *b*.	Blue clay	2
Bed *c*.	Somewhat marly, false-bedded, oolitic limestones	3
Bed *d*.	Blue compact limestones	1
Bed *e*.	Blue clay	3
Bed *f*.	Blue argillaceous limestone (recognizable in the Hanborough Well-section). *Rhynchonellæ* and spines of *Echini* are abundant	1
Bed *g*.	Very hard, compact, blue-hearted limestone, in three bands, showing the false bedding only after prolonged weathering.[1]	14
Bed *h*.	Blue clay about	3[2]

The thicknesses are considerably greater than in any of the Forest-Marble exposures on the east.

(*i*) Hanborough Quarry (at the cross-road to Eynsham, east of the Railway-Station).

About 2 feet of rubbly, very fossiliferous Cornbrash forms the subsoil of this section.

The Forest Marble consists of 4 feet of blue clay, resting upon compact, shelly, oolitic limestones, in which the false bedding is apparent only after prolonged weathering; the thickness of limestone exposed does not exceed 10 feet.

[1] Included in the Great Oolite by A. H. Green, 'Geology of the Country round Banbury, &c.' Mem. Geol. Surv. 1864, p. 27; see also E. Hull, 'Geology of the Country around Woodstock,' Mem. Geol. Surv. 1859, p. 23.

[2] [A well now being sunk within 200 yards of the quarry has shown that the thickness of clay is very irregular, varying from 2½ to 4 feet, the lower part being very marly. The clay rests upon an extremely irregular surface of the Fossiliferous Cream-Cheese Bed, which is here about 12 inches thick; this rests upon marly limestones, of which only a thickness of 2 feet has at present been pierced.—*September 30th, 1913.*]

(*j*) Hanborough Well, by the Station cottages.

The thicknesses are given by the well-sinker; and, as he is a quarryman in the Bladon and Gibraltar quarries, his descriptions are to be relied on.

		Approximate thickness in feet.
Rubbly limestone (Cornbrash):	same as top of Bladon Quarry	8
Bed *a*.	Stiff blue clay, passing into rock	12
Bed *b*.	Shelly blue limestone	2
Bed *c*.	Compact limestone	6
Bed *d*.	Clay	3

On the evidence of the well-sinker, the blue argillaceous limestone (Bed *f*) of Bladon Quarry is the same as the shelly blue limestone (Bed *b*) in the well; I was fortunate enough to be able to verify this.

(*k*)[1] Hanborough Quarry (near Mill Wood): western end of Long Hanborough.

There are two quarries close together, which yield the following section.

Southern Quarry.

		Thickness in feet	inches.
	Gravel	5 to 6	0
Cornbrash.	Impersistent clay	0	6
	Marl with *Microthyris lagenalis*	0	8
	Compact limestone yielding *Pseudomonotis echinata*.[2]	6	0
	Dark clay-band	0	4
	Terebratula-intermedia Limestone.	2	0 (seen)

Northern Quarry.

		Thickness in feet	inches.
	Gravel	0 to 1	0
Cornbrash.	Limestone with *Pseudomonotis echinata*	2 to 3	0
	Dark clay	0	4
	Terebratula-intermedia Limestone	3	0
Forest Marble.	Bluish-grey clay	3	4
	Coarse, shelly, oolitic limestone.	4	0 (seen)

(*l*) Woodstock Railway-Cutting.

A cutting on the Woodstock Branch of the Great Western Railway has been described by Mr. H. B. Woodward.[3] The full thickness of the Cornbrash was here found to be 11 feet 8 inches, while that of the Forest Marble is stated to be 19 feet 6 inches.

The Great Oolite was exposed for a depth of about 30 feet; the top bed is evidently the same as the oolitic type of the Fossiliferous Cream Cheese of Gibraltar Quarry; also the bed with *Astarte* and *Gervillia* is evidently Bed 5, and the bottom bed the Second *Terebratula* Bed of the above-named quarry.

[1] Misprinted (*h*) on the map (fig. 1, p. 486) north-west of the word Long in 'Long Hanborough.'

[2] A fragment of an ammonite has been obtained from this bed; from the description given to me I have little doubt that it is *Clydoniceras discus*.

[3] 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iv (1894) pp. 447, 373, 374, & 320.

Notes on other Sections.

There are now no sections exposed in the Stonesfield district. The sequence, however, at Stockey Bank, Stonesfield (*m*) has been worked out by a committee of the British Association.[1]

It may be summarized as follows:—

> Limestones and marls, with many globose forms of *Rhynchonella.*
> Stonesfield Slate Series.
> Neæran Beds: green, black, and grey clays and limestones.
> Chipping-Norton Limestones.

The sequence round Chipping Norton has been fully worked out by Mr. L. Richardson,[2] who largely confirms and adds to Mr. Walford's observations.[3] The sequence is similar to that at Stonesfield, except that the Stonesfield Slates are entirely or almost absent. The accounts supplied of well-sections are for the most part so vague as to be of little value.

The descriptions given of the topmost bed of the Great Oolite suggest that the 'Cream-Cheese' or 'Fossiliferous Cream-Cheese' type of rock extends over a large area, occurring as far east as Witney and Bampton.

On the south, in the boring at the Oxford City Brewery,[4] the Cornbrash is seen to be 17 feet thick, while 32 feet 8 inches is assigned to the Forest Marble.

In assigning 88 feet to the Great Oolite, it is probable that the Fuller's-Earth Rock and the '*Rhynchonella* Beds' have been included. The $28\frac{1}{2}$ feet of beds described as belonging to the Upper Estuarine Series are extremely suggestive of the Neæran Beds of Ardley.

The 16 feet of rock described as Inferior Oolite seems to agree more closely with the Chipping-Norton Limestone: the fragments of the cores preserved in the Museum of Practical Geology, Jermyn Street, London, do not resemble the *Clypeus* Grits of Fawler.

The borings at Calvert (*n*), recently described by Dr. A. M. Davies & Mr. J. Pringle,[5] are of great interest, the absence of the Cornbrash and possibly of the lower beds of the Oxford Clay being remarkable, as is the thickening of the Forest Marble.

The absence of Neæran Beds bears out the evidence of unconformity noticed in the Ardley section.

From the evidence of the specimens kindly shown to me by Dr. A. M. Davies, I am inclined to think that the Fullonian type of deposit predominated here until a later period, to the exclusion of true Great Oolite.

[1] Rep. Brit. Assoc. (Oxford) 1894, p. 304; *ibid.* (Ipswich) 1895, p. 415; and *ibid.* (Liverpool) 1896, p. 356.

[2] 'Inferior Oolite & Contiguous Deposits of the Chipping-Norton District' Proc. Cotteswold Nat. F. Club, vol. xvii, pt. 2 (1911) pp. 195 *et seqq.*

[3] 'On some New Oolitic Rocks in North Oxfordshire' Buckingham, 1906.

[4] R. H. Tiddeman, 'Water-Supply of Oxfordshire' Mem. Geol. Surv. 1910, p. 65.

[5] Q. J. G. S. vol. lxix (1913) p. 310.

IV. Palæontology.

Cornbrash.

The Cornbrash has yielded a very rich fauna of a constant character, the same assemblage being found in almost every exposure.

The most noticeable absentees are the Cephalopods, which have only been recorded from Witney and Woodstock,[1] where *Macrocephalites macrocephalus* and *Clydoniceras discus* occur. The latter is also recorded from Kidlington.[2] This might be explained by the fact that in most of the exposures only the lower beds are exposed; but the explanation is not wholly satisfactory, since *M. macrocephalus* and *Cl. discus* certainly occur very near the base in the Fleet, Weymouth.

Most of the thirty-seven species mentioned in the Geological Survey Memoir[3] as being the most abundant and characteristic species of the Cornbrash occur; and of the eighty-eight species recorded, the following fifteen occur in almost every exposure:—

Pseudomonotis echinata (Sow.).
Gresslya peregrina Phil.
Homomya gibbosa Sow.
Modiola imbricata Sow.
Pleuromya securiformis Phil.
Camptonectes lens (Sow.).
Pecten vagans Sow.
Lima gibbosa Sow.
Pholadomya deltoidea Sow.
Terebratula intermedia Sow.
Ornithella obovata (Sow.).
Serpula tricarinata Sow.
Echinobrissus clunicularis (Lhwyd).
Pygurus michelini Cott.
Anabacia orbitulites Lam.

Of the eighty-eight species recorded, no less than seventy occur in the Cornbrash of Islip and Kidlington.[4]

Forest Marble.

The fauna of the Forest Marble is comparatively poor, consisting of but forty species, of which only the following nine are at all common:—

Camptonectes lens (Sow.).
Gervillia waltoni Lyc.
Modiola imbricata Sow.
Pecten fibrosus Sow.
Pecten vagans Sow.
Ostrea sowerbyi Lyc.
Rhynchonella concinna auctt.
Acrosalenia (spines).
Pentacrinus (columnals).

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[1] H. B. Woodward, 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iv (1894) p. 446.

[2] J. F. Blake, 'Fauna of the Cornbrash' Monogr. Pal. Soc. 1905, p. 54.

[3] H. B. Woodward, *op. supra cit.* p. 434.

[4] J. F. Whiteaves, 'Invertebrate Fauna of the Lower Oolites of Oxfordshire' Rep. Brit. Assoc. 1860 (Oxford) Trans. Sect. p. 107.

It is to be noticed that such forms as *Dictyothyris coarctata*, *Zeilleria digona*, and *Eudesia cardium* have only been recorded from Islip,[1] while *Apiocrinus parkinsoni* has been recorded from one of the clay-bands at Kirtlington, ? Oxford Portland-Cement Works,[2] but from which is uncertain; probably it came from one of the bands in the Great Oolite, Block 1. Although *A. parkinsoni* has usually been considered a Bradford-Clay fossil, Prof. Reynolds & Dr. Vaughan have shown that the Bradford-Clay fauna occurs at several horizons in the upper part of the Great Oolite;[3] and so there is no justification for assuming from the occurrence of this form the presence of a definite horizon.

Great Oolite.

The fauna of the Great Oolite (as defined in this paper) includes about ninety species. In addition, nineteen species have been recorded from the lower beds; but these probably came from the beds here classed as Fullonian.

In the Great Oolite, when subdivided, we find that Block 1 is chiefly characterized by *Nerinæa eudesii*, while in Block 2 *N. funiculus* is the more characteristic fossil; *Clypeus mulleri* only occurs in the lower part of Block 2, and has not been found in the upper beds: that is, not above the *Nerinæa* Rock.

Block 3 is nowhere exposed, except in the Ardley section, where it will soon be obscured by the downwash of the clays; it is characteristically unfossiliferous, except for a few very badly preserved fossils.

Fullonian.

Palæontologically, in this district the Fullonian is best considered as being composed (1) of an upper series, including all the beds down to the top of the Stonesfield Slates; (2) the Stonesfield Slates; and (3) a lower series, consisting of the Neæran Beds and the Chipping-Norton Limestone. The upper series contains forty-five species, while the Stonesfield Slates contain 194 species, and the Neæran Beds contain forty-eight: since some of the species occur in more than one division, the total fauna of the Fullonian amounts to 245 species. Of this total ten are restricted to the upper beds, 133 to the Stonesfield Slates, and eighteen to the lower beds of the district.

On reviewing the assemblage of fossils from the Bathonian rocks of the district, we find that of the 370 species recorded, 224 are restricted in range; of these no less than 133 are restricted to the Stonesfield Slates, and thirty-four to the Cornbrash. Of the 370,

[1] J. F. Whiteaves, 'Invertebrate Fauna of the Lower Oolites of Oxfordshire' Rep. Brit. Assoc. 1860 (Oxford) Trans. Sect. p. 107; and H. B. Woodward, 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iv (1894) p. 376.

[2] *Id. ibid.* p. 375.

[3] S. H. Reynolds & A. Vaughan, Q. J. G. S. vol. lviii (1902) p. 742.

only about eighty can be said to be at all common. Palæontologically, the only beds that can be recognized are as follows:—

Cornbrash, characterized by	*Pseudomonotis echinata*, *Gresslya peregrina* *Terebratula intermedia*, *Ornithella obovata* and *Pygurus michelini*.
Great Oolite. Block 1.	*Gervillia waltoni*, *Nerinæa eudesii*, and *Terebratula bathonica*.
1st & 2nd '*maxillata*' Beds.	*Terebratula bathonica*, large and abundant.
Nerinæa Rock.	*Nerinæa* cf. *funiculus*.
Fullonian. *Rhynchonella* & *Inoceramus* Beds.	*Inoceramus obliquus*, *Rhynchonella* sp., *Clypeus mulleri*, and *Ostrea sowerbyi*.
Stonesfield Slates, characterized by	*Trigonia impressa*. *Gervillia acuta*, and *Stigoceras micromphalus*.

R. F. Tomes[1] mentions thirty-four species of corals from the Bathonian, and divides them into seven bands, according to the localities from which they came. Of these, No. 1 is probably below the Stonesfield Slates, while Nos. 2, 3, & 4 are probably of the same age, since Mr. Walford mentions a coral-bed at Stonesfield just above the 'slates',[2] and on his own showing No. 2 is precisely in that position. Nos. 5 & 6 probably represent the coral-bed in Gibraltar Quarry, which grew on the eroded surface below the First *Terebratula* Bed, and the coral-bed in the Fossiliferous Cream-Cheese Bed of the Oxford Portland-Cement Works. Bed 7 occurs in the Cornbrash at Fairford; this latter is of interest, since *Stylina* and *Thamnastræa arachnoides* are recorded from the Cornbrash near Buckingham.[3] *Th. arachnoides* is so typically Corallian, where it occurs with *Stylina delabechei*, that one feels some doubt as to whether this does not represent a small faulted outlier of Corallian.

A peculiar Structure referred to Annelid-Tubes from Bed *k* of the Chipping-Norton Limestone of the Ardley Section. (Pl. XLVIII, figs. 3 & 4.)

In this rock, which is a fine-grained argillaceous limestone, a number of curious circular rings of coarse material are seen in section. A vertical section shows that these rings are produced into a tube, the total length of which is unknown.

The external diameter of the rings varies in different specimens from 10 to 20 mm.; the length, so far as can be seen, is about 30 mm. When the rock has become disintegrated by wet and frost, these tubes are found to be closed in at the base. A microscope-section shows them to be composed of small shell-fragments

[1] Q. J. G. S. vol. xxxix (1883) pp. 178–74.
[2] E. A. Walford, Rep. Brit. Assoc. (Oxford) 1894, p. 304; *ibid.* (Ipswich) 1895, p. 415; and *ibid.* (Liverpool) 1896, p. 356.
[3] A. H. Green, 'Geology of the Country round Banbury, &c.' Mem. Geol. Surv. 1864, p. 32.

and oolitic grains arranged with their long axes parallel to the walls of the tube, so as to present a smooth surface internally; the fragments all show evidence of having been rolled and coated, so as to form ooliths with one thin coat; typical ooliths also occur.

Towards the base of the tubes the fragments are arranged in such a manner as still to present a smooth surface internally; that is, the fragments forming the extreme base of the tube are arranged with their long axes at right-angles to those that form the sides.

These tubes are very numerous in the Chipping-Norton Limestone of the Ardley section, and an apparently similar structure occurs in the Great Oolite of the Portland-Cement Works Quarry.

It is impossible to state definitely how these tubes were formed; but they bear a certain resemblance to the tubes constructed by such varieties of annelids as *Terebella* and *Sabella*, so abundant on recent sea-shores.

V. Chemical Composition.

The chemical examination of the rocks has in certain instances greatly facilitated the microscopic examination. In cases where the matrix is more or less opaque, it is impossible to distinguish between clay and amorphous carbonate of lime. The 'Cream-Cheese Bed,' for instance, in thin section appears to be extremely marly; but the analysis has shown that 93·5 per cent. is composed of carbonates of calcium and magnesium.

The proportion of magnesium carbonate was found to be so small (usually less than 1 per cent.), that after the first thirty analyses only the insoluble residue, iron, and alumina were calculated; it was found that the iron and alumina, which were estimated together, were always in proportion to the amount of insoluble residue if it consisted of clay, but not if it consisted of quartz-grains. The most interesting results are obtained by considering the insoluble residue, iron, and alumina together. When this was done, it was ascertained that the Cornbrash from two exposures, namely: Islip and the Portland-Cement Works, has approximately the same composition, containing the following percentages of clay, iron, and alumina:—

Cornbrash, Islip	8·53
Cornbrash, Portland-Cement Works	7·927

In the Forest Marble the sequence in different parts of the same quarry is so variable, that no result of any value could be expected, even from numerous analyses.

The marly bands from the Upper Green-Hill Quarry, namely, C_2 and D_3, yielded the following residue, iron and alumina, which was almost entirely clay.

	Per cent.
C_2	51·24
D_3	21·01

From the limestones the following percentages of insoluble residue, iron and alumina, were obtained:—

Hanborough	6·27
Portland-Cement Works	4·83

In the Great Oolite the results were more interesting, the Fossiliferous Cream-Cheese Bed having practically the same composition in Gibraltar Quarry as in the Ardley section.

	Ardley. Per cent.		Gibraltar. Per cent.	
Residue insoluble in hydrochloric acid	1·33	4·58	1·39	4·59
Ferrous carbonate	0·43		0·40	
Ferrous oxide, alumina, and phosphates	2·82		2·80	
Calcium carbonate	94·38		94·67	
Magnesium carbonate	0·39		0·41	

The two *Terebratula* Beds in Gibraltar Quarry are found to have a very similar composition, the percentage of clay, iron, and alumina being as follows:—

First *Terebratuta* Bed	14·94
Second *Terebratula* Bed	16·64

The *Nerinæa* Rock becomes slightly more marly when traced from east to west, as the following results show (insoluble residue):—

	Per cent.
Gibraltar	4·71
Portland-Cement Works	5·04
Ardley	5·75

Since none of the beds below this are exposed in different sections, it is not possible to institute any comparisons. In the Ardley section the compact limestones of the lower part of Block 2 vary in containing from 90 to 92 per cent. of calcium and magnesium carbonates. In Block 3 occur the least calcareous beds of the Great Oolite; the six beds from the Ardley section that have been analysed show the following percentages of insoluble residue, iron, and alumina; the residue in Bed 22 is entirely clay, but in the other beds consists chiefly of quartz.

	Per cent.		Per cent.
Bed 22	78·08	Bed 25	22·62
Bed 23	25·32	Bed 26	5·59
Bed 24	16·67	Bed 27	20·04

In the Fullonian of Ardley we find the following percentages:—

Bed 29	43·69	Bed 31 Fuller's-Earth Rock	16·88
Bed 30	41·52	Bed 34 *Rhynchonella-Inoceramus* Beds	25·29

In the Neæran Beds the percentage of clay, etc. is very high, being anything between 58 and 91, except in the case of the *Astarte* Bed, where it is only 31·24. The green coloration appears to be due to ferrous carbonate.

The Stonesfield Slates vary considerably in composition, the insoluble residue being chiefly quartz.

The following table gives the percentage composition of the types examined:—

	Residue insoluble in hydrochloric acid.	*Iron and alumina.*
Sandy bed in Stonesfield 'Slates'	46·75	1·47
Fine-grained 'slate'	3·31	1·26
Medium-grained 'slate'	19·73	4·96
Coarse-grained 'slate'	12·14	3·60
Coarse-grained 'slate' enclosing pebble...	21·09	5·75
Pebble from the above	11·94	4·84
Pebble from another specimen	5·96	2·02

VI. Petrology.

The microscopic examination of the Bathonian rocks has brought out to a marked degree the prominent part played by the Echinodermata in the building of the Bathonian limestones; except for a few minor bands, quartz is found only in the lower beds of the Great Oolite and in the Fullonian, and bedding is also only noticeable in these same rocks.

The purer limestones may be divided into three main groups:—

(1) In which the matrix consists for the most part of amorphous carbonate of lime.

(2) In which the matrix is entirely crystalline.

(3) In which the matrix is partly recrystallized from an originally amorphous form.

Of those belonging to the first group, the most interesting are the Cream-Cheese Bed and the Fossiliferous Cream-Cheese Bed: the latter being practically uniform in character, both chemically and microscopically, from all the exposures.

Of the seventy microscope-sections examined only four can be said to belong strictly to the second group; this includes the shelly equivalent of the Fossiliferous Cream-Cheese Bed of Gibraltar Quarry, also Beds 3 & 19 of the Ardley section.

In the lower beds of the Great Oolite and in the Fullonian, angular quartz-grains are usually abundant; this is especially true of the Stonesfield Slates, where the ooliths are often formed round grains of quartz.

In the coarse type of the Stonesfield Slates numerous rolled pebbles occur, as also irregular concretionary masses; in section, these appear to consist of a rock somewhat similar to the fine-grained type. The irregular shape of some of these suggests that they were formed by contemporaneous rolling of the mud in the watercourses, and that they are not fragments of older beds.

Quartz is abundant, and, in addition to the small shell-fragments, numerous small ooliths occur; fragments of echinoderms are by no means uncommon, and in one section a small portion of a fish-tooth is seen.

Through the kindness of Dr. F. A. Bather, F.R.S., I was able to have sections cut of several echinoderm-spines, with the view of identifying those seen in the rock-sections; but, since I was unable to obtain specimens from some of the commoner Bathonian genera, it was found impossible to identify them. Sections across different parts of the same spine show so different a structure, that no evidential value can be attached to them, unless a very large number be examined.

In all the ooliths found in the Bathonian rocks, the concentric layers are well shown, but no *Girvanella* structure has been seen; those from the coarse type of the Stonesfield Slates are by far the largest, and usually show radial as well as concentric structure. They are generally formed round shell-fragments or small rolled fragments of rock, resembling the matrix in which they are embedded.

VII. Correlation, and Conditions of Deposition.

The correlation of the exposures in the district are most readily seen by reference to the two subjoined tables (figs. 4 & 5, pp. 508 & 509); it therefore only remains to indicate their relation to other areas, together with the conditions prevailing in the Oxford district during their deposition.

The Chipping-Norton Series appears to be purely local, and to be represented only in the Chipping-Norton and Oxford districts, while the Neæran Beds seem to be equivalent to the *acuminata* zone: that is, just above the Fuller's-Earth Rock of Dorset (S. S. Buckman, *in litt.*); on the north-east they keep approximately the same character, and are readily recognized as the Upper Estuarine Series in the Great Northern Railway cuttings north of Peterborough, where one band, the *Astarte* Limestone, is palæontologically and lithologically almost indistinguishable from that seen at Ardley.

The Stonesfield Slates are known in the Cheltenham district, where between them and the Fuller's-Earth Rock occurs a very fossiliferous band crowded with *Ostrea* and *Rhynchonella*, which Mr. Richardson designates 'the *Rhynchonella-concinna* Bed.' A similar bed occurs above the Neæran Beds round Chipping Norton, and at Ardley; in the Calvert Boring it rests almost directly on Chipping-Norton Limestone, and at Stonesfield on the Stonesfield Slates.

The Fuller's-Earth Rock, both of Somerset and of the Cotteswolds, is characterized by *Teloceras subcontractum*, as are the Weatherstones and Shell Beds of Minchinhampton, and appears to come into line with Bed 31 at Ardley (L. Richardson, *in litt.*).

The whole group described as Upper Fullonian (Upper Beds of fig. 5, p. 509) can be paralleled with the Great Oolite Clay and Great Oolite Limestone resting on the Upper Estuarine Series north of Peterborough, where, however, *Rhynchonellæ* are practically absent, although they are abundant in the same beds at Oundle.

Fig. 4.—*Vertical sections illustrating the correlation of the principal exposures in Oxfordshire of Cornbrash and Forest Marble.*

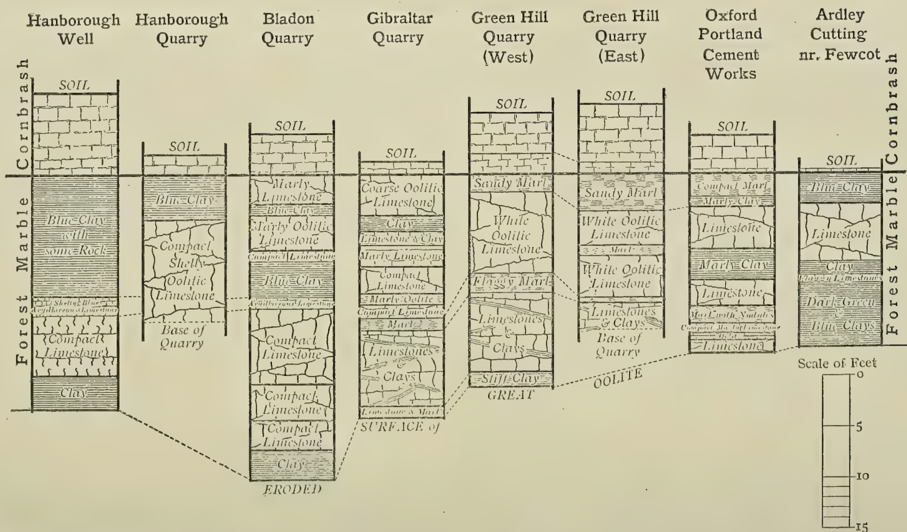
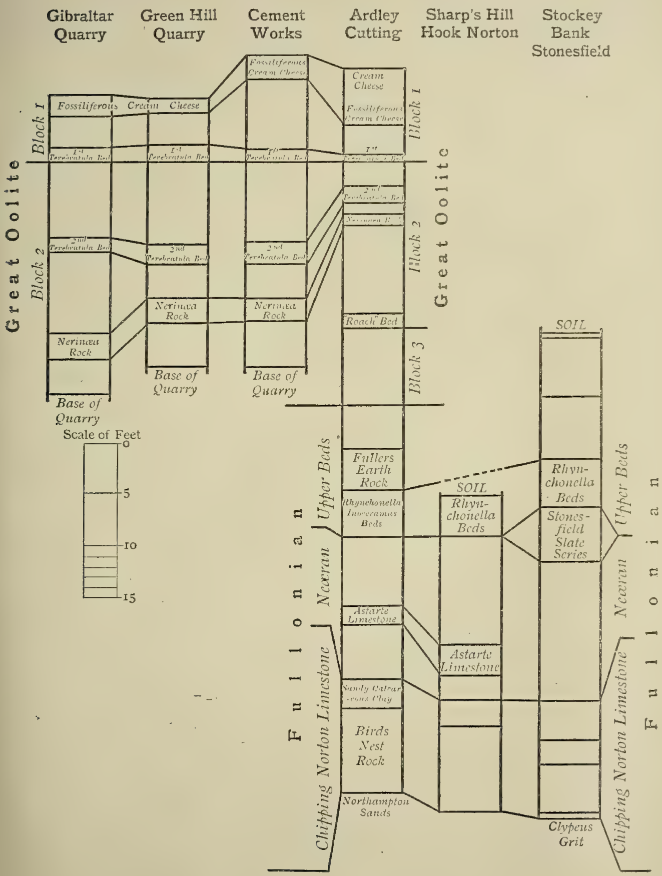


Fig. 5.—*Vertical sections illustrating the correlation of the principal exposures in Oxfordshire of Great Oolite and Fullonian.*



The beds in the Great Oolite cannot be correlated in detail; but Mr. Richardson considers that Bed 21 of Ardley (the Roach Bed) may represent the Dagham Stone of the White Limestone division in the neighbourhood of Cirencester.

North of Peterborough these beds do not appear to me to be represented, the Cornbrash resting directly on the so-called 'Great-Oolite' clays. Except in two places (see p. 502), the Bradford-Clay facies does not seem to be developed; while, but for their very small thickness, the Forest Marble and Cornbrash are apparently quite normal.

In order to understand the conditions prevailing during the deposition of the Bathonian rocks in the Oxford district, it is necessary to consider what conditions prevailed during previous times. At Fawler there is evidence that a barrier was being formed a short distance away to the north; the rising of this barrier caused the Middle, and more especially the Upper, Lias to be very thinly deposited, so much so that in a band only 3 inches thick, among others, the following ammonites occur:—*Harpoceras* cf. *falciferum*, *Dactylioceras commune*, and *Hildoceras bifrons*. Above this band comes about 12 feet of unfossiliferous clay, followed by the Upper *Trigonia* Grit and *Clypeus* Grit, which form the *Parkinsoni* Beds of the Inferior Oolite, this zone overlapping all the lower zones.

During the same time, north of this barrier, sands, for the most part unfossiliferous, were being deposited, which have usually been called the 'Northampton Sands,' although in reality they are not equivalent to the true Northampton Sands, which are of earlier date, but are in part homologous with the *Clypeus* Grits, as Mr. Walford has shown.[1]

These North Oxfordshire Northampton Sands (to use the general term, since no distinctive name has been assigned to them) are well exposed near Westcott Barton and at the tunnel-mouth near Fritwell in the Ardley section. South of this there is no definite record of them; they certainly do not occur in the Oxford City-Brewery Well, and it is extremely doubtful whether they occur as far south as Bicester, although the well-section at Gowell Farm and Upper Arncot suggests their presence.[2]

We see, then, that a ridge lay north of Fawler and Stonesfield, curving round to the south of Fritwell, and possibly passing under Bicester; north of this ridge bands of sand were deposited, while on the south the *Clypeus* Grits were deposited, the latter probably thinning-out towards Stonesfield and not being laid down as far east as Oxford.[3]

[1] 'On the Relation of the so-called "Northampton Sand" of North Oxon to the *Clypeus* Grit' Q. J. G. S. vol. xxxix (1883) p. 224.

[2] R. H. Tiddeman, 'Water-Supply of Oxfordshire' Mem. Geol. Surv. 1910, pp. 26, 29, 67.

[3] The absence of Neæran Beds in the Calvert Boring suggests that the boring lies on this ridge, which continued to assert itself certainly until late Stonesfield-Slate times.

On the *Clypeus* Grits and Northampton Sands lie a series of beds, chiefly calcareous, forming the Chipping-Norton Limestone, which have been exposed round Chipping Norton, at Fawler, Stonesfield, and in the Ardley section; and they probably also occur under Oxford. This is followed by the Neæran Beds, predominantly green clays containing wood as well as numerous dwarfed oysters (*Ostrea sowerbyi*), and resembling the oyster-banks of the Lower Fullonian near the Fleet, Weymouth. Upon these south of the ridge were laid the Stonesfield-Slate beds, which probably do not extend far east, north, or south of Stonesfield, nothing that resembles them being recorded in any of the well-sections.

The coarse oolitic nature of some of the beds, together with the rolled fragments, suggests shallow water, and possibly the ridge on the north continued to rise, thus cutting off mud from that direction; while proximity to land is suggested by the very large percentage of angular quartz-grains and the perfect preservation of delicate land-plants, as also by the abundance of insect-remains.

The fact that the teeth of Pycnodont fishes are found embedded in the rock in their natural relative positions shows that the current cannot have been strong, although deposition must have been rapid. Unfortunately, nothing is known of the Stonesfield Slates in this district except from Stonesfield; and thus it is impossible to trace their thinning-out, or to arrive at any conclusion as to where the quartz came from. The beds seem to have been laid down in shallow water not far from land, while the abundance of sand and plant-remains suggests that the river which brought down the material probably entered the sea not far off.

The *Rhynchonella-Inoceramus* Beds (Beds 33–35 of the Ardley section) seem to have been deposited right over this ridge, and to have been but slightly influenced by it.

The thinning of the upper beds of the Great Oolite towards the north-east is suggestive of a land-surface in that direction, an inference which is further borne out by the apparent absence of these beds north of Peterborough.

Throughout the Great Oolite Period in the Oxford district, the beds were apparently deposited in water that was shallow, but still sufficiently deep to prevent them from accumulating under the influence of shifting currents.

The alternations of horizontal bedding with marked false bedding in the Forest Marble seem to suggest violent oscillations of the currents, possibly due to periodic changes in the level of the sea-floor; while the thinning of the Cornbrash towards the suggested position of the ridge and its entire absence at Calvert, imply that, for a time, the folding along the ridge reasserted itself. It should be noticed that Mr. Buckman considers the absence of Cornbrash in the Calvert boring to be due to the denudation of an anticlinal fold previous to the faulting (see Q. J. G. S. vol. lxix, 1913, p. 341). Personally, I consider that thinning-out of the Cornbrash (owing to non-deposition on the axis of the fold), followed by subsequent faulting, is a simpler explanation.

EXPLANATION OF PLATES XLVII & XLVIII.

Plate XLVII.

Fig. 1. Exposure in Upper Green-Hill Quarry, eastern end.
2. Exposure in Lower Green-Hill Quarry.

Plate XLVIII.

Fig. 1. Cornbrash from Hanborough Quarry. near the railway-station; × 16. Two large ooliths, probably derived, occur near the top; the rock consists, for the greater part, of small shell- and echinoderm-fragments in a somewhat marly matrix; echinoderm-fragments are most abundant towards the bottom and left-hand edges.
2. Stonesfield Slate enclosing a pebble; × 16. The 'slate' consists of small shell-fragments and quartz-grains, together with numerous ooliths and one large echinoderm-fragment near the top towards the right; the pebble consists of small shell-fragments and abundant quartz-grains, without any ooliths.
3. Transverse section of the annelid-tube described on pp. 503 & 504; × 4½. This shows the concentric arrangement of the particles; the irregularly-arranged material on the left-hand half of the central portion has evidently fallen in.
4. Longitudinal section of the above, showing the arrangement of the fragments parallel with the length of the tube. × 4½.

Discussion.

The Secretary read the following letter, received from Mr. S. S. Buckman:—

'The abstract of the paper on the Bathonian rocks of the Oxford district appears to indicate that the Author has accomplished an important piece of work. The geology of that district is little known in detail, except from a paper by Mr. E. A. Walford read before, but unfortunately not published by, the Society[1]—a paper written before the cuttings on the new railway gave a further insight into the sequence, which is a great advantage to present-day investigators. The present Author seems to have been able to confirm Mr. Walford's sequence.

'When the Author states that "although no definite zones can be formulated, the different horizons are readily recognizable by their assemblage of fossils," he seems to be under some misapprehension as to a zone. The different assemblages of fossils are the local zones: their correlation with the zonal system of the similar strata on the south-west should present no difficulty, and, if stated, would give to the paper greater value and a wider interest. Besides, ammonites from these strata have been obtained by other investigators, which would yield further evidence for fixing zones.

'A particular interest in the strata of this district is the position of the Neæran Beds, already ascertained from Mr. Walford's researches. They link up the marine Fullers' Earth strata of the south-west with the Upper Estuarine deposits of Yorkshire, and thus enable the date to be fixed for the Yorkshire beds.

'The Author's use of the term '*Concinna* Beds' is inadvisable. *Rhynchonella concinna* is a species of the Cornbrash. Various more or less *concinna*-like *Rhynchonellæ* are found in earlier rocks, but to give them the name of the Cornbrash species is misleading. There is a somewhat large inconstantiform *Rhynchonella* which occurs in, and is characteristic of, certain Fullers' Earth deposits of the Ardley Cutting. So far as I know, it does not occur in other districts; but it should not be called *Rh. concinna*.'

[1] [This paper, under the title of 'Some New Oolitic Strata in North Oxfordshire,' was afterwards privately printed: Buckingham, 1906.]

FIG. 1. UPPER GREEN HILL QUARRY, EASTERN END.

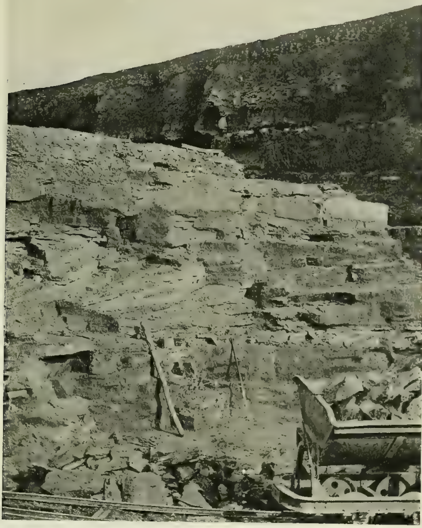


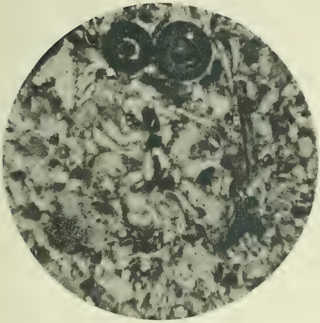
FIG. 2. LOWER GREEN HILL QUARRY.

M.O. Photo.

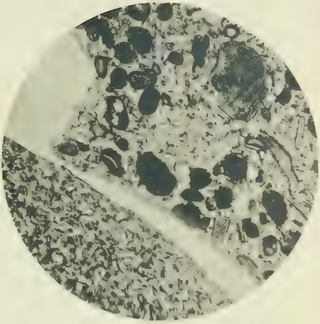
Bemrose, Collo. Derby.

Bed 4, the 1st TEREBRATULA Bed, cannot be seen in this photograph, since quarrying operations have left a platform which cuts it out of view.

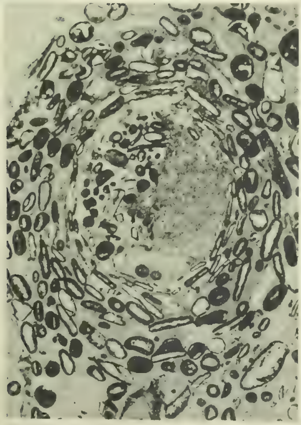
1. × 16



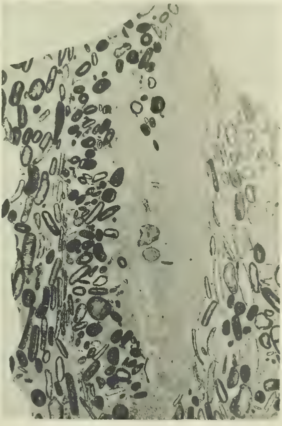
2. × 16



3. × 4¼



4. × 4¼



M.O. Photo.

Bemrose, Collo., Derby.

ROCKS AND ANNELID (?) TUBES FROM THE OXFORD BATHONIAN.

Dr. A. M. Davies said that he only knew the fringe of the district described, but was impressed with the resemblance of many of the specimens and microscopic sections exhibited to those obtained from corresponding strata in the Calvert boring. The rarity of ammonites in the Cornbrash had been mentioned; yet he had obtained several examples of *Clydoniceras* from Blackthorn Hill.

Mr. J. Pringle remarked that he was interested in the Fritwell-Ardley section described by the Author. During the progress of the excavations he (the speaker) had examined the beds in company with Mr. George Barrow. The measurements obtained did not appear, however, to coincide very closely with those given by the Author.

The Author thanked the Fellows present for the reception given to his paper. Then, in reply to Mr. Buckman's letter, he said that, with reference to the expression that no definite zones could be formulated, he intended to convey the idea that no single fossil had a sufficiently restricted range. With regard to the term '*Concinna* Beds,' he would be very glad to substitute the term '*Inoceramus-obliquus* Beds'; but he had adopted the designation '*Concinna* Beds,' since that term had been already used for these beds. In reply to Dr. Davies, he said that the absence of Cornbrash was exceedingly interesting: he would have rather expected the Forest Marble to be absent.

23. *The* Geology *of* Bardsey Island.

By Charles Alfred Matley, D.Sc., F.G.S.; *with an* Appendix *on the* Petrography, by John Smith Flett, M.A., D.Sc., F.R.S., F.G.S.

(Read February 26th, 1913.)

[Plates XLIX & L.]

Contents.

I. Introductory Remarks.

Bardsey, an island a mile and three-quarters long, and covering approximately an area of 500 acres, is the westernmost fragment of North Wales, and lies about 2 miles from the promontory of the Lleyn (Western Carnarvonshire), from which it is separated by Bardsey Sound. Its Welsh name, Ynys Enlli, or the Island of the Current, has reference to the strong tides that sweep between its shore and the mainland.

Mynydd Enlli, the dominant topographical feature of Bardsey, lies in the north-east of the island, and forms a bold ridge running nearly due north and south. It rises precipitously above the eastern line of sea-cliffs to a height of 548 feet O.D., and descends more gradually on its western side to about 100 feet O.D., where it passes into cultivated drift-covered ground. At the harbour of Henllwyn, the larger and northern part of the island in which this 'mountain' is situated is connected by an isthmus, at its narrowest some 35 yards wide, with the smaller southern portion, which consists of a rather flat tract having an elevation of about 50 to 60 feet O.D.; on this portion the lighthouse is built. The southern extremity has been so much dissected by sea-erosion, that the strip of slates between the heads of the opposing inlets of Ogof Lladron and Ogof Diban is only 40 feet wide.

Geologically, Bardsey has long been recognized as forming the isolated extremity of the 18-mile-long strip of ancient rocks that borders the western coast of the Lleyn from Nevin south-westwards. The geology of the whole of this strip has been under investigation by me for some time, and I hope to present my results at a not far distant date. Meanwhile, an account of the structure and rocks of Bardsey may be of interest to geologists, as affording an epitome of the geological phenomena and yielding many of the rock-types of the adjacent mainland.

II. History of Previous Researches.

Our present knowledge of the geology of this island is derived from the Geological Survey 1-inch map (quarter-sheet 76, S.) and from short descriptions to be found in the following works:—

1843. Sedgwick, A.—'Outline of [the] Geological Structure of North Wales' Proc. Geol. Soc. vol. iv, p. 213.
1866. Ramsay, A. C.—'Geology of North Wales' Mem. Geol. Surv. vol. iii, pp. 169–70; also 2nd ed. (1881) p. 212.
1888. Blake, J. F.—'On the Monian System of Rocks' Q. J. G. S. vol. xliv, p. 531.
1893. Raisin, Miss C. A.—'Variolite of the Lleyn & Associated Volcanic Rocks' Q. J. G. S. vol. xlix, p. 160.
1909. Jehu, T. J.—'The Glacial Deposits of Western Carnarvonshire' Trans. Roy. Soc. Edin. vol. xlvii, pt. 1, pp. 28–29.

Sedgwick grouped the rocks of Bardsey with those of the coastal strip of the neighbouring mainland as 'chlorite and mica-slate,' and correlated them with 'a formation which is widely expanded in the Isle of Anglesea' (*op. supra cit.* p. 213). As regards their position, he considered that they were 'inferior to the other slate rocks in the southern promontory of Carnarvonshire' (*ibid.* p. 219). The island was mapped (about 1850) by Mr. A. R. Selwyn, whose MS. notes supplied the information for the following short account given in Ramsay's Survey Memoir of 1866, in which the beds are classified as 'metamorphosed Cambrian':—

'Bardsey.—The east coast of Bardsey Island consists of "green, grey, and purple siliceous schists and slaty rocks, patches of quartz rock, and a few thin grey calcareous bands, all much contorted on a small scale, without affecting the general north-westerly dip." A lenticular piece of marble occurs on the coast about half way between Ogof-Morlâs and Pen Cristin. At Bay-y-Nant the dip is easterly. On the west the rocks are of the same description. The whole undulates in various contortions' (pp. 169–70).

In the 2nd edition Sir Andrew Ramsay added that the rocks 'chiefly consist of highly metamorphic strata of a rudely gneissic character.' He also gave a short account of the glaciology of the island.

Blake placed the Bardsey rocks in the 'Volcanic Facies' of his Monian System. He records 'large agglomerates with calcareous and quartzose patches' on the eastern side of the island; and 'on the slope of the hill and by the lighthouse, low quartz-knobs of the usual isolated form and characteristic structure.'

Miss Raisin's description, given after a 'somewhat hurried' examination, refers to the agglomerate, tuff, and green diabase at the extreme southern point and to 'well-banded ashy rocks' in the same neighbourhood; draws attention to the 'coarser agglomerates (including large compact blocks and streaky laterite) which' can be seen from a boat to 'form the eastern cliffs north of Yr-Henllwyn'; and mentions the discovery of a granitic or granitoid rock at three localities. She regards the rocks in the main as part of a volcanic series, those in the south being

apparently the lowest strata exposed, in view of the fairly steady dip of the beds over most of the island.

Dr. Jehu's work in Bardsey dealt exclusively with the drift and the glacial phenomena, and will be referred to later.

III. Stratigraphy of the Pre-Cambrian Rocks.

The rocks of the island consist principally of sediments, usually green, gritty, schistose slates or phyllites, in and among which occur irregular beds, lenticles, and masses, large and small, of quartzite, grit, and limestone. Igneous rocks are also present. Granite, diabase, and spilite, nearly always much crushed by earth-movement, have been observed, and there are also dykes of olivine-dolerite, quite uncrushed and therefore of post-movement age. The sediments have, it is true, the prevalent westerly to northerly dip mentioned by earlier writers, but no general inference as to the succession can be drawn from this fact, for the field-work reveals frequent inversions and repetitions of the strata. The structure is often masked by slaty cleavage, and the rocks in many places are in a thoroughly cataclastic condition. The rocks have been subjected to intense earth-pressure acting mainly from the north-west, with the result that they have been disrupted, overfolded, and overthrust. All the pre-movement rocks are, for reasons given below, considered to be of pre-Cambrian age; but the age of the movements themselves will not be here discussed.

There is a close lithological resemblance, as earlier writers have pointed out, between these rocks and those of the northern district of Anglesey; and, from my knowledge of both regions, I am able to state that this resemblance extends also to the manner in which both areas have been affected by intense earth-movements. Just as in the Cemaes area of Northern Anglesey, rocks once regarded as volcanic agglomerates have proved to be cataclastic sedimentary strata,[1] so also in Bardsey, although volcanic rocks do occur in the island, I have failed to recognize any true agglomerates, and I find that those which have been described as such are bedded rocks which have been torn to pieces by earth-movement, and are now in the condition of crush-breccias and crush-conglomerates. Similarly, the isolated 'quartz-knobs' of J. F. Blake, of which several good examples occur in Bardsey, prove to be, as in Northern Anglesey and elsewhere, portions of massive beds of quartzite that have been broken up into lenticles and separated from their fellows by differential movements between these hard masses and their less rigid associates.

The rocks are excellently exposed on the shore and in the sea-cliffs, but inland, except on Mynydd Enlli, they are largely covered by boulder-clay. The accompanying coast-sections (figs. 1, 2, & 3, pp. 517, 520) are given, in order to illustrate the geological structure;

[1] See Sir Archibald Geikie, Geol. Mag. ser. 4, vol. iii (1896) p. 481; and C. A. Matley & W. W. Watts, Q. J. G. S. vol. lv (1899) pp. 657–66 & 677–78.

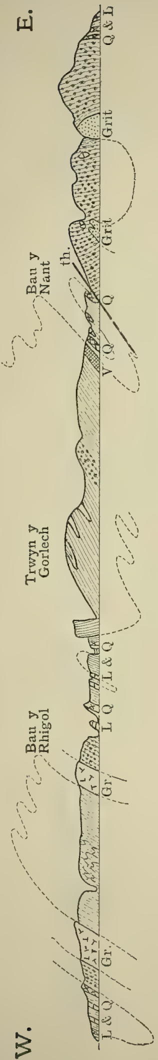


Fig. 1.—*Section on the north coast of Bardsey.* (*Length=about two-thirds of a mile.*)

[Gr = Granite. L = Limestone. Q = Quartzite. V = Variolite.]

and they, as well as the map (Pl. L), should be referred to when the following description is read. It is not claimed, however, that the folding indicated in these sections is more than semi-diagrammatic, it being impossible to determine in many cases whether the isoclinal folds (which are themselves much broken) are anticlines or synclines.

(*a*) The Northern Coast. (Fig. 1.)

In the north-western corner of the island, in the cliffs between Ogof Lâs and Bau y Rhigol, the granite discovered by Miss Raisin is exposed at five localities, but these exposures may represent no more than a single sill repeated by folding. Thus, when the two granite-bands and the associated sediments on the northern shore are examined, the succession of the beds (fig. 1) is seen to be such as it would be if they were disposed in an isoclinal fold, whether anticline or syncline. Between the granite-bands occur thinly and evenly-splitting, well-cleaved, green, sandy slates, which are often white-crusted and weather to a buff colour; they contain a central zone with quartzite-bands that exhibit overfolding. Beyond the granite-bands, in the same order on each side, are cataclastic slates and grits, followed by a slaty zone with thick quartzite and limestone in large lenticles and broken beds. The western band of granite is a sill about 100 feet thick, with a west-north-westward dip at 60° to 80°, its lower edge following closely, though with slight transgression, the cleavage-planes of the slates. It is traversed by thrust-planes which have driven it and the overlying beds south-eastwards for short distances; it is fissile as though roughly cleaved, and is so much crushed as to present under the microscope the appearance of a breccia. The eastern granite-band is narrower, being about 40 feet thick, but the difference in thickness offers no special obstacle to the suggestion

that it is the same sill as the western band: for even the sedimentary rocks of the island vary remarkably in thickness (as will be shown later), when followed for very short distances along their strike—owing to deformation by earth-movement. This eastern sill is intersected by veins of coarser and paler granite and by lenticular quartz-veins, and becomes finer in texture towards the margins. It is sheared, and shows, under the microscope, severe crushing and advanced 'mortar-structure.' When all the foregoing facts are taken into consideration, the most reasonable explanation of the geological structure seems to be that the sill and its associates have been folded together.

The quartzite-and-limestone zone mentioned above is cut out eastwards by a thrust, which introduces green white-crusted slates without limestone; in places these slates are cataclastic: they contain many lenticles and broken bands of grit and quartzite, and in part they are so sandy as to become cleaved fine-grained sandstones. Under them comes an interesting igneous rock, which can be traced from the shore inland for about 150 yards. It is a crushed, purple-and-green, compact, basic rock, some 6 to 10 feet thick, made up of phacoids, and showing under the microscope variolitic structure in places. It may be a crushed pillow-lava like those described by Miss Raisin[1] from the adjacent mainland, or possibly a sill. As there is some shearing at the base of this variolite, a thrust may separate it from the underlying rocks, which consist of broken beds of quartzite and grit and an occasional limestone-nodule in a slaty matrix. The latter beds are thrust, at the head of Bau y Nant, over similar cataclastic rocks that form the northern slope of Mynydd Enlli, which, however, contain in addition a broken massive bed of crushed gritty sandstone, seen in two places. On the east is a crush-conglomerate containing pieces of quartzite, grit, and limestone.

Whereas the cleavage-planes (and the bedding-planes, where seen) of the beds west of the Bau-y-Nant thrust dip almost invariably westwards, those east of the thrust dip almost as consistently eastwards at a high angle. The Bau-y-Nant thrust can be traced southwards on the western slope of Mynydd Enlli for at least three-quarters of a mile.

(*b*) The Western Coast. (Part of fig. 2 & fig. 3, p. 520.)

Along the western coast, between the north-western corner and Porth Solfach, the rocks exposed correspond in the main with those just described as occurring on the northern shore. The granite is found associated in the same manner with the evenly-cleaved green sandy slates, with the more irregularly-cleaved phacoidal and cataclastic slates and grits, and with the zone of thick limestone and quartzite-lenticles already described. There is also to be seen, about 100 yards south of Ogof Gwr, a few feet of a rock that seems

[1] Q. J. G. S. vol. xlix (1893) pp. 148 *et seqq.*

to be a crushed pillow-lava (spilite) brought up by a thrust from the north. This rock may be correlated with the variolite already seen in Bau y Nant, as it is similarly overlain by siliceous slates which are practically cleaved sandstones. The latter are contorted.

South of these is to be seen on the shore a conspicuous group of thick lenticles of quartzite dipping westwards at about 40° to 50°. They represent a broken-up bed about 7 feet thick. A limestone-band, also now represented by isolated lenticles, lies in the slates a few feet below the quartzite. Still farther south, in Porth Solfach, granite is exposed again, as shown by Miss Raisin, at and near high-water mark; I found it also at low-water mark at Trwyn Dihirid, and at the next point to the north-west of it, dipping north-westwards at 65° to 75°. At all these localities it is crushed and cataclastic, as also are its sedimentary associates.

From the south side of Porth Solfach to the lighthouse, a distance of 800 yards, irregular beds and lenticles of quartzite and limestone occur among slates which, as a rule, are more irregularly cleaved and contorted in the immediate neighbourhood of the larger lenticles. Close to the lighthouse is a massive quartzite 20 feet thick, dipping north 15° west at an angle of 65°. Separated from this bed by a narrow interval of highly-contorted slates with thin flaggy quartzite-bands, is another quartzite of irregular thickness up to 15 feet, dipping in the same direction at 45° to 50°. I consider the two quartzites to be probably a single bed repeated by a broken isoclinal fold, especially as limestone occurs under the southern and above the northern of these two outcrops. Lenticles among the slates and limestones in the rocks on the north can be identified with the same bed, indicating additional broken isoclines.

The coast south of the outcrop of the 20-foot quartzite-bed is eroded in white-weathering siliceous slates, like those seen in the north of the island at and near Trwyn y Gorlech. They contain one or more zones of quartzose flags, the rapid isoclinal folding of which brings out the structure of the slates; broken bands and lenticles of quartzite, and a zone of flaggy grits that forms several irregular outcrops, are also present. At the southernmost extremity of the island (Maen Dû and neighbourhood) there has been much movement, thrust-planes abound, and the rocks are considerably shattered, sheared, and cut up into lenticles, the dynamic forces acting from the north-west and west. Here and at Ogof Lladron, green diabase is found associated with a green phacoidal crush-breccia of greenish-grey grit in a slaty matrix. A portion of the igneous rocks here present a phacoidal aspect, and it is just possible that this may be crushed pillow-lava; but much of the igneous material in this area is almost certainly intrusive, and the sediments in contact with some of the diabase have been converted into chert-like adinoles. The diabase occurs in a manner suggesting that it forms broken synclines lying among overfolded slates.

Fig. 2.—*Section from the south-eastern coast of Bardsey to the north-western corner.* (*Length = about a mile and a half.*)

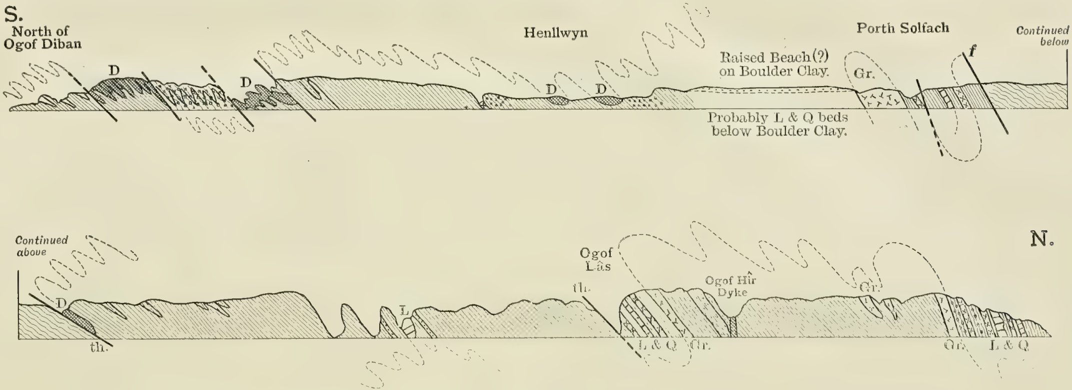
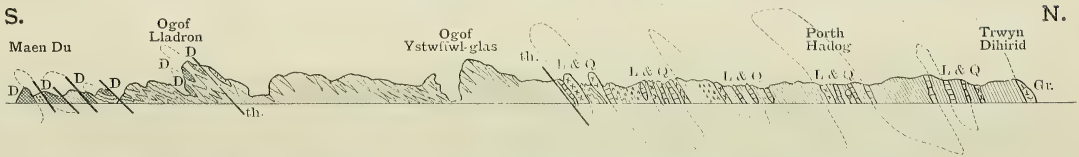


Fig. 3.—*Section along the south-western coast of Bardsey.* (*Length = about three-quarters of a mile.*)



[D = Diabase and variolite. L = Limestone. Q = Quartzite. Gr = Granite. th. = thrust-planes.]

(*c*) The South-Eastern Coast. (Part of fig. 2, p. 520.)

This shore consists mainly of the siliceous slates with their usual quota of grit- and quartzite-bands, already described as occurring on the south-western coast; but diabases also occur, in two long strips separated by a slaty crush-conglomerate that contains abundant quartzite and rare lenticles of limestone. These diabases undoubtedly belong to the same group as those seen about Maen Dû. They have often a sheared aspect, and pass into 'schalsteins'; parts of them look pillowy and may be lavas, but some of the masses are intrusive. They contain bands and lenticles of chert-like sediment, apparently folded intensely, and these seem to be contact-altered rocks or adinoles. Some of the igneous rocks distinctly cut across the bedding, and form lenticular sills.

Farther north-west, in the bay of Henllwyn, a large mass of pillowy diabase or spilite, showing remains of vesicular and variolitic structure, occurs below high-water mark, and there may be more lenticles at that locality; but the rocks are obscured by thick growths of *Fucus*. Grit, slate, and some calcareous sandstone are also in evidence, the whole being broken up into a crush-breccia.

From the shore-sections just described, it will be apparent that, despite a fairly constant direction of dip, there is much repetition of the strata, evidently the result of overfolding and overthrusting. The following rock-groups are recognizable, and seem to occur in the order shown below:—

(vii) Cataclastic grits and slates, with occasional limestone.
(vi) Variolite and diabase, partly as intrusive sills and partly as pillow-lava (spilite).
(v) Gritty slates and fine-grained sandstones, usually showing regular cleavage and containing thin flaggy quartzite and grit-bands.
(iv) Limestone-and-quartzite group: that is, slates with included thick beds and lenticles of quartzite and limestone.
(iii) Cataclastic grits and slates.
[Granite-sill intruded usually at about this horizon.]
(ii) Sandy slates, showing regular cleavage.
(i) Sandy slates, with quartzite-bands.

(*d*) Mynydd Enlli.

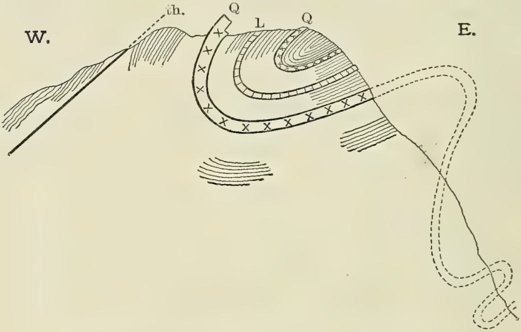
A thrust-plane hading westwards can be followed, as already stated (p. 518), from Bau y Nant in a southerly direction. It can be traced along a bracken-clad hollow on the western slope, and divides the hill structurally into two portions. It reaches the shore near the harbour of Henllwyn, and may be continued across the bay as one of the thrusts that traverse the south of the island with a west-south-westerly course.

The western, or overthrusting, limb consists of cataclastic green slates, with one or more purple zones, enclosing many small phacoids of grit and occasional larger lenticles of flaggy grit, quartzite, and limestone. The cleavage, usually phacoidal, dips at 30° to 40° west

to north-west. There is a small quarry in these slates, about 50 yards south-east of the school, exposing a purple igneous rock which microscopic examination shows to be a fine-grained decomposed variolite. It underlies a tufaceous shale containing pebbles of the same rock with chert and some sediment, and so there is no doubt that the igneous rock in this case is a lava and not a sill.

On the east the beds below the thrust-plane dip at higher angles, usually from 60° to 90°, and the dip is generally a reversed one. A conspicuous outcrop of quartzite about 8 feet thick helps us to elucidate the structure here. On the crest, south of the summit, at about 300 feet O.D., the quartzite stands up as a prominent rock, and can be followed along the hill-slope as a sigmoidal fold, as shown in fig. 4. Though broken by a fault, this bed can be traced

Fig. 4.—*Sigmoidal fold on the ridge of Mynydd Enlli, at the 300-foot contour, looking north.*



[Q = Quartzite. L = Limestone. th. = thrust-plane.]

northwards for a distance of about 400 yards as a group of thick lenticles which lie between the crest and the sole of the thrust. Still farther north several more large lenticles or 'quartz-knobs' are to be seen, one of which is represented in Pl. XLIX, fig. 2. They may be portions of the same bed. Two other fine examples of large isolated lenticular masses are perched, one near the other, on the steep slope above Ogof Morlâs, and dip east-north-eastwards at 40° to 50°. One is of quartzite, the other of limestone.

On the bare northern slopes of the hill cataclastic gritty slates dip steeply, though with many minor contortions and small overfolds, below the two great lenticles just mentioned. They contain the usual broken bands of grit and quartzite; while a zone of thin, flaggy, quartzose grits and lenticles of a fine clastic breccia (or angular grit) make their appearance in places. At the northern

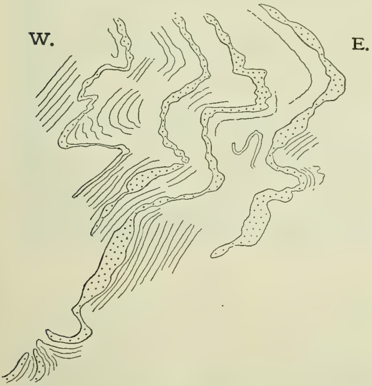
summit, in the core of an overfold, a highly-vesicular, rotten, basic igneous rock, presumbly a pillow-lava, occurs in association with limestone and quartzite. Not far away, near the 505·5-foot bench-mark, is a dyke-like mass of diabase, some 25 to 30 feet wide, referred to by Dr. Flett in the Appendix (p. 530). The adjacent slates show contact-alteration.

The steep eastern face of Mynydd Enlli has not been examined by me, but the rocks are seen from the sea to be mainly cataclastic slates frequently containing masses of quartzite and limestone. Towards sea-level the structural planes dip westwards at moderate angles. On the shore at Bau Felen occur some ferruginous ochreous rocks which may be basalts, but I was unable to examine them. Farther south the coast is occupied by great crush-conglomerates of quartzite and limestone in a slaty matrix, which can be conveniently studied on the headland of Pen Cristin.

(*e*) The Crush-Conglomerates of Pen Cristin.

Between Henllwyn and Pen Cristin some stages in the process of disruption which has given rise to the formation of these crush-conglomerates can be traced. The shore-section here is remarkably like, and is as instructive as, that exposed on the shores of Cemaes Bay (Anglesey).[1] North-east of the harbour of Henllwyn the quartzite and limestone group is well exposed, as thick beds contorted, folded, sheared, and broken into lenticles, lying among slates with irregular and contorted cleavage. Farther east come slates with numerous broken bands and long lenticles of quartzite and occasional lenticles of limestone, which exhibit overfolding (fig. 5). At Pen Cristin they give place to more thoroughly cataclastic strata, consisting of a slaty matrix full

Fig. 5.—*Overfolding in quartzite-bands interbedded with slates; cliff west of Pen Cristin.*

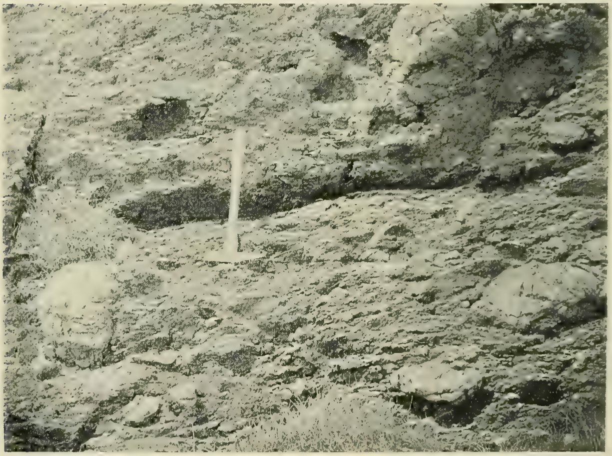


[The longest band shown is some 20 feet in length.]

[1] Described by me in Q. J. G. S. vol. lv (1899) pp. 661–65. As the limestones and quartzites of Bardsey are precisely like those of Northern Anglesey, no lithological description is given of them in the present paper.

of inclusions of grit, quartzite, and limestone, sometimes rudely phacoidal, sometimes irregular, and often more or less rounded, and of all sizes from large 'boulders' to tiny 'pebbles' (fig. 6, below). Yet, even in these shattered strata, traces of overfolding can be seen, as fragments of the same limestone-band recur again and again at various heights and at various places in the cliffs. Cataclasis of the strata is admittedly due to the crumpling effect of compression acting differentially on hard, brittle, and less yielding beds (the grits and limestones) when interbedded with softer and more extensible slates, with the result that the former have broken up and the latter have flowed round the fragments.

Fig. 6.—'*Crush-conglomerate' in the cliff at Pen Cristin.*



C. A. M. photo.

In this locality the disruption seems to have acted along the septa of small overfolds or buckles in steeply dipping beds.[1]

Fig. 1 of Pl. XLIX represents a portion of a cliff—not on Bardsey itself, but on the adjacent mainland near St. Mary's Well, south-west of Aberdaron. It has been introduced to show the passing of interbedded bands into a crush-conglomerate, and also the deformation of a massive bed of quartzite into two wedges.

[1] See G. Barrow, 'On Buckled Folding' Geol. Mag. dec. 5, vol. ix (1912) p. 518.

IV. Post-Movement Intrusions.

Three olivine-dolerite dykes with a north-westerly to south-easterly trend have been noted in the course of the mapping. They are quite uncrushed, and occupy fissures which cut across the structures of the surrounding strata. One of them, some 40 feet or more wide, has been excavated by the sea to form the little harbour at Cafn Enlli. Another but narrower dyke is seen in the cliff-fissure of Ogof y Gaseg: it splits into two branches, both of which die out before reaching the top of the cliff. The third dyke, 9 feet wide, occupies the fissure-indentation in the coast at Ogof Hîr. In addition, I have detected two small bosses of similar dolerite on the western slope of Mynydd Enlli.

On the shore at Briw Gerig, east of Mynydd Enlli, as seen from a boat, are many blocks of a basaltic rock which may be a thick dolerite-dyke; on the other hand, it may be one of the older diabases.

V. Stratigraphical Summary.

From the foregoing description it will be seen that the rocks of Bardsey have been shattered by earth-movements, which have acted from directions between north and west. So great is the shattering that almost everywhere the harder bands, whether thick or thin, that were interbedded in the slates have been torn to pieces, and lie as detached blocks and lenticles in the softer slaty strata. The general tectonic arrangement, though to a great extent masked by this local shattering, has been shown to consist of a number of broken overfolds, which are accompanied by thrusts. The rocks themselves are mainly gritty schistose slates, with many thin and some thick bands of grit, quartzite, and limestone. They contain an horizon of variolitic lava and tufaceous shale which indicates that a volcanic episode occurred during their formation. Except in this last-mentioned zone, the bedded rocks seem to be ordinary sediments; some pyroclastic fragments probably occur in them, but they are not conspicuously present. There are, however, sills of albite-diabase folded in with the sedimentary strata, as also one or more sills of a crushed granite.

From the nature of the brecciation and the comparatively small amount of mineral change which the beds have undergone, it is inferred that the load of superincumbent rock at the time of the principal earth-movements was not great.

In order to ascertain the age of the beds, we must go to the mainland, where there is evidence that rocks precisely similar to those in Bardsey had been altered to their present condition and denuded before Lower Arenig times, as many fragments of the schistose slates and grits, in the condition of sericitic phyllite, quartz-granulite, etc., occur in a Lower Arenig breccia on the promontory about 2 miles north-east of Bardsey.[1] From a consideration of the

[1] C. A. Matley, 'The Arenig Rocks near Aberdaron' Geol. Mag. dec. 4, vol. ix (1902) p. 122.

known Cambrian rocks of North Wales it is clear that the Bardsey and Lleyn rocks must be of pre-Cambrian date. The intrusive diabase and granite-sills may be also of pre-Cambrian age.

The sedimentary rocks of Bardsey can be correlated with the lower beds of the Llanbadrig Series of Northern Anglesey and with their equivalents, the Llanfair-y'nghornwy Beds of North-Western Anglesey. In the latter area there is also, as in Bardsey, an intrusion of granite which has undergone much crushing, and it may, perhaps, be correlated with the Bardsey granite.

As regards the post-movement dolerite-dykes, similar dykes can be seen in large numbers in the pre-Cambrian strip of the neighbouring mainland, where I have mapped about 125 of them. They are most probably of Tertiary age, as already suggested by Mr. E. Greenly for dykes of the same composition and with similar trend in Anglesey,[1] and Dr. Flett writes to me concerning a rock-slice from one of the Bardsey dykes [9091],[2] that it is an

'ophitic olivine-dolerite with fresh basic felspar, extraordinarily like some Tertiary dolerite-dykes of the West of Scotland.'

VI. Glaciology.

In the 2nd edition of his North Wales Memoir Ramsay mentioned the Glacial drift of Bardsey, and observed that the island

'has been moulded by ice . . . . , but the mammillated roches moutonnées have since been roughened by the weather.' (*Op. cit.* p. 212.)

The only other reference to the glaciation is in Dr. Jehu's paper of 1909, where he remarks that

'the island as a whole may be regarded as an example of the phenomenon known as "crag and tail," the crag facing the north-east, from which direction the ice-sheet came.' (*Op. cit.* p. 29.)

Among the boulders and pebbles recorded by him from the boulder-clay of the island may be mentioned Chalk-flints, Ailsa Craig microgranite, Dalbeattie granite, picrite, Carboniferous Limestone, and shell-fragments.

The result of my own investigation of the drift-phenomena of the Island is given below. Glacial drift, in the form of boulder-clay, covers most of the ground between Mynydd Enlli and the western coast, the mountain itself being almost free from drift, though its rocks are frequently moutonnées. The drift-covered area is given over to agriculture. In the south of the island the drift is patchy and very thin. Ice-worn surfaces are common, though few of them have retained their scratches. I found striæ, however, at

[1] 'On the Age of the Later Dykes of Anglesey' Geol. Mag. dec. 4, vol. vii (1900) pp. 160–64.

[2] The numbers in square brackets here and in the Appendix are the numbers of the rock-slices in the Museum of Practical Geology, Jermyn Street, cut from material handed over to that Museum from my collection.

five localities,[1] and they all indicated movement of the ice to the east of south, not to the south-west as previously supposed. The suggestion quoted above that Mynydd Enlli affords an example of 'crag-and-tail' structure falls, therefore, to the ground; in fact, the roches moutonnées on its eastern slopes are worn parallel to the trend of the ridge and not across it.

As Dr. Jehu had already investigated the sources of the Bardsey boulders, I contented myself with collecting a few specimens from the boulder-clay of Porth Solfach and neighbourhood, and sent them to my friend Mr. E. Greenly for comparison with Anglesey rocks and boulders, as it seemed highly probable that the ice-sheet that invaded Bardsey had previously passed over Anglesey. His determinations are interesting, as they enable the movement of the ice-sheet to be defined very closely. Two of the pebbles are red granites of typical 'Mona' type, while a third of fine-grained granite is also a Mona granite. An augen-gneiss pebble may have been derived from the Anglesey gneisses, but Mr. Greenly is more inclined to regard it as derived from the Scottish Highlands. Other Anglesey rocks identified are Ordovician grit and slate, and white cherty shale from the top of the Carboniferous Limestone. Other specimens, including Chalk-flints, occur as boulders in Anglesey, and only two specimens (a purple rhyolitic felsite and a yellowish grit) are unknown to him. Now, the Mona granite is practically confined to a belt in Central Anglesey which has a south-westerly trend corresponding with the general trend of the ice-sheet in that region, and Ordovician grits and slates lie on the flank of the granite, while Carboniferous Limestone lies on the north-west. The portion of the Irish-Sea glacier that invaded Bardsey must, therefore, have passed over Anglesey to the west of Red Wharf Bay. The course of the ice-sheet across Anglesey was in a south-westerly direction; and this course is now shown to have been deflected in Carnarvon Bay to a direction east of south, a deflection which seems to have been caused by pressure from the ice that radiated from the east of Ireland. It was previously known that Irish ice had forced the Irish-Sea ice into South Wales, across Cardigan Bay into North Pembrokeshire;[2] and it is of interest now to find that the pressure has also left its traces in this little westerly outpost of North Wales.

[1] The localities are:—The coast north of Mynydd Enlli; Hen-dy; Porth Solfach, near the granite; near Trwyn Dihirid; and the coast east of the lighthouse.

[2] See T. J. Jehu, 'The Glacial Deposits of Northern Pembrokeshire' Trans. Roy. Soc. Edin. vol. xli, pt. 1 (1904) p. 53, and previous literature quoted therein. As a contribution of my own ('On the Geology of Part of North-East Pembrokeshire' Proc. Birm. Nat. Hist. & Phil. Soc. vol. x, pt. 2, 1897, pp. 92–101) was inadvertently overlooked in that paper, I hope that I may be excused for mentioning that I had previously proved the former presence of Irish-Sea ice in the north-east of that county. [Attention is also invited to the Discussion, pp. 532–33, both as regards the former presence of Irish-Sea ice in Merionethshire, and as to the cause of the deflection of that ice into Cardigan Bay.]

VII. The Post-Glacial Raised Beach (?).

The isthmus between Porth Solfach and Henllwyn forms the lowest part of the island, with a level about 18 to 20 feet above Ordnance datum. The low cliffs on each side are excavated in boulder-clay, on which lies at several places a shingle resembling a thin beach-deposit. I also found sand containing marine shells in one of the fields about here. It seems not unlikely, therefore, that we have at this spot a relic of the post-Glacial 25-foot beach so well-known on the east coast of Ireland; but the evidence is, to my mind, not strong, and I should like to have confirmatory evidence of a similar beach on the neighbouring mainland of North Wales before definitely adopting this explanation. One would expect, for instance, that when the sea was at raised-beach level the scour of the tides between the two islands into which Bardsey would have been divided would have swept out the boulder-clay. One has also to consider the possibility that the shingle and sand may in recent times have been cast over the isthmus during storms, or even that the shingle may have been spread artificially along shore cart-tracks now cut into by coast-erosion.

Mr. Fearnsides has recently recognized some features on the coast east of Criccieth, which suggest to him a post-Glacial rock-platform about 10 feet above tide-level.[1] This level corresponds fairly well with that of the Bardsey platform, so that further work in the Lleyn may establish a post-Glacial raised beach in Bardsey beyond reasonable doubt.

In conclusion, I wish to express my warmest thanks to Dr. J. S. Flett for undertaking the examination of the rocks and for contributing an Appendix on the Petrography, and to Mr. Greenly for his comparison of the Bardsey drift-pebbles with Anglesey rocks and boulders. My best thanks are also due to Mr. Herbert H. Thomas, Sec.G.S., for supervising the preparation of the colour-printed map, and to the Assistant Secretary for his care in seeing the paper through the press during my absence in India.

VIII. Appendix on the Petrography. [J. S. F.]

(1) The Granites.

The granite that forms the sills or veins on Bardsey Island is pale, usually greyish green from the abundance of chlorite. It is neither coarsely crystalline nor porphyritic, and all the specimens examined have a crushed or broken appearance, although there is nothing like a well-developed or regular foliation. Occasionally, the granite is so much shattered, with broken felspar-crystals lying in a dark-green chloritic matrix, that it becomes very similar in appearance to a crushed felspathic grit [9090, Porth Solfach].

[1] 'The Tremadoc Slates & Associated Rocks of South-East Carnarvonshire' Q. J. G. S. vol. lxvi (1910) p. 184.

The various specimens selected for slicing are so like one another in composition and structure, that there is no difficulty in believing that they are all of closely allied origin; they may, in fact, represent one sill repeated by folding.

Both muscovite and biotite are present in the slides, the latter being the more abundant, though it is practically always replaced by chlorite. Part of the muscovite is primary, but there is also secondary white mica developed from the felspar. The rock has contained much orthoclase, though this is seldom in good preservation, being mostly converted into 'shimmer-aggregates' of sericite. A fresh polysynthetic felspar is also common, and proves on being tested always to be albite. Zircon, iron-ores, and sphene are the accessories, and, in addition to sericite and chlorite, sometimes epidote, rutile, limonite, and carbonates occur as secondary minerals.

The structure is cataclastic in a high degree, the quartz being crushed, the felspar broken and sericitized, and the mica drawn out into irregular wisps and streaks. Some of the slides show a good deal of fine granulitic material, consisting of quartz, felspar, and white mica. The granitic structure is often sufficiently clear however, especially at Ogof Hir [9293] and Bau y Rhigol [9288].

Towards the margins of the sills there is a development of a porphyritic facies, which has an abundant microcrystalline or felsitic matrix with phenocrysts of original muscovite, in addition to quartz and felspar [9289, north-western corner of the island; 9291, Ogof Hir].

The question arises whether the granite has any connexion with the pillow-lavas and diabases. In several parts of Britain (Tayvallich,[1] Porthallow[2]) granitic rocks occur intrusive into pillow-lavas, in such a way as to suggest that they are of kindred origin. These granites are generally rich in soda, and contain much albite. The Bardsey granite has a fair amount of albite, though not so much as the 'soda-granite' of Porthallow. It seems quite likely, although in the circumstances it cannot be definitely proved, that in Bardsey Island also the pillow-lava eruptions terminated by the intrusion of an acid magma, now represented by the Bardsey granite.

(2) The Pillow-Lavas and their Tuffs.

The rocks of this group are much altered by decomposition and by pressure. Their felspars are replaced by sericite and carbonates; their femic minerals by carbonates and chlorite; their iron-ores by leucoxene and limonite. Little of their original structure remains, except traces of phenocrysts and of amygdaloidal cavities filled with calcite and chlorite. Crushing has gone so far as to produce a well-marked cleavage, and in some cases an irregular schistosity. Many

[1] 'The Geology of Knapdale, Jura, & North Kintyre' Mem. Geol. Surv. Scot. 1911, p. 93.

[2] 'The Geology of the Lizard & Meneage' Mem. Geol. Surv. 1912, p. 186.

of the rocks might be described as calc-chlorite schists. In places a broken crystal of albite is left in these sheared rocks, and indicates the original igneous structure. It would be difficult, in fact, from the microscopic slides alone to recognize many of these rocks as pillow-lavas; and it is impossible to discuss adequately what was their original composition and structure.

It is clear, however, that there were porphyritic and non-porphyritic types, the former containing felspar phenocrysts and the latter being often very vesicular. The pillow-lavas are extremely liable to alteration, and, in fact, are nearly always much decomposed; and this, in addition to their highly vesicular character, makes them weak rocks, which are very readily crushed by folding movements. From the northern summit of Mynydd Enlli some of the specimens [9303] are exceedingly like the more completely altered vesicular schalsteins of Cornwall and Devon,[1] such as occur around Brent Tor.

A specimen obtained 50 yards south-east of the school is interesting, as exhibiting traces of the variolitic structure which is so characteristic of the pillow-lavas of the Lleyn[2] and Anglesey.[3] Another specimen from the same locality contains fragments of glassy variolite; this resembles the 'palagonitic tuffs' that accompany pillow-lavas in the Mevagissey[4] and Porthallow[5] districts of Cornwall.

(3) The Diabases.

Most of the basic volcanic rocks of Bardsey Island are so fine-grained and so highly vesicular that they are more probably lavas than intrusions. None of the specimens sliced is a typical albite-diabase,[6] such as those that occur so commonly among spilitic rocks elsewhere. There is, however, one remarkable rock from Mynydd Enlli, near the 505·5 bench-mark [9302], which is rather coarsely crystalline, and shows one of the characteristics of the 'spilitic suite' in that it is exceedingly rich in albite. It contains also chlorite, iron-ores, and a fair amount of quartz; and it has been so much crushed that it resembles a breccia rather than an igneous rock. This rock is abnormal among albite-diabases in containing much primary quartz, and perhaps micropegmatite; but no doubt can be entertained that it is intrusive, and closely connected in origin with the pillow-lavas.

A chert-like rock, associated with a green diabase north of

[1] 'The Geology of Dartmoor' Mem. Geol. Surv. 1912, p. 20.

[2] Miss C. A. Raisin, 'Variolite of the Lleyn & Associated Volcanic Rocks' Q. J. G. S. vol. xlix (1893) p. 152.

[3] E. Greenly, 'The Origin & Associations of the Jaspers of South-Eastern Anglesey' Q. J. G. S. vol. lviii (1902) pp. 429–30.

[4] 'The Geology of the Country around Mevagissey' Mem. Geol. Surv. 1907, p. 54.

[5] 'The Geology of the Lizard & Meneage' Mem. Geol. Surv. 1912, p. 184.

[6] H. Dewey & J. S. Flett, 'On some British Pillow-Lavas & the Rocks Associated with them' Geol. Mag. dec. 5, vol. viii (1911) p. 206.

Fig. 1.—*Interbedded bands passing into 'crush-conglomerate.'*

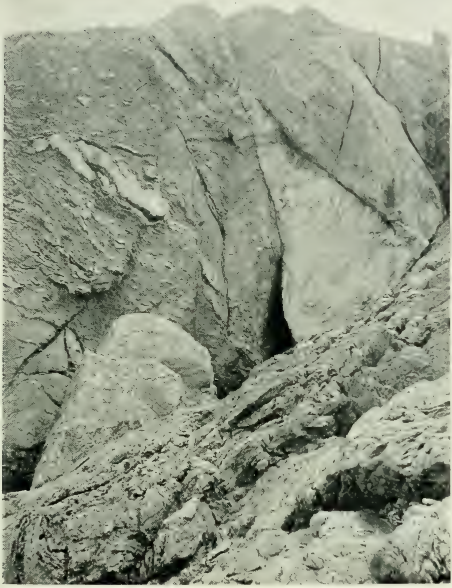


Fig. 2.—*'Quartz-knob' on the western slope of Mynydd Enlli.*

C. A. M. photo.

Maen Dû [9306], contains a good deal of felspar in very minute grains, and proves to be an adinole. It is readily fusible before the blowpipe, and represents a shale altered by contact with an intrusive diabase.

EXPLANATION OF PLATES XLIX & L.

Plate XLIX.

Fig. 1. Interbedded bands passing into 'crush-conglomerate,' as seen in the coast-section near St. Mary's Well, south-west of Aberdaron. The photograph also shows the deformation of a massive bed of quartzite into two wedges. (See p. 524.)

2. 'Quartz-knob' on the western slope of Mynydd Enlli. (See p. 522.)

Plate L.

Geological map of Bardsey Island, on the scale of 12 inches to the mile, or 1 : 5280.

Discussion.

Mr. G. Barrow said that he regarded the paper as of extreme importance, as it dealt with one of the torn-out and piled-up masses of rock that accompanied the movement of great crystalline portions of the earth's crust. For the meaning of it one had to go to Anglesey, where there was one of these great crystalline areas, within which newer rocks of varying ages had been dropped down by faults. Of these, the variolites or pillow-lavas, mentioned by the Author, had been described by Mr. Greenly in a paper read before the Geological Society. On the north-west side of the Menai Straits denudation had laid bare the base of the heaped-up mass, the last remnant of which was seen there in contact with the outer or uncrystalline margin of the Archæan area. The great crystalline mass had snapped off at this margin, and a thrust-plane had developed. As the mass slowly glided along this it bent, buckled, and finally broke up into lenticles the rocks that lay in its path, heaping them up, and forming the confused medley of rocks described by the Author. The phenomena were similar to those met with along the southern Highland Border (seen in the North Esk), and along portions of the Moine Thrust. All were connected with, and marked the position of, the outer margin of crystallization of one of the older Archæan complexes.

Mr. W. G. Fearnsides wished to associate himself with the congratulations to the Author expressed by the previous speaker. The detailed record of the structures exhibited by the old rocks in Bardsey would supply a want, long felt by workers who were trying to puzzle out structures in the less well-exposed districts of the mainland of Wales.

To the speaker, the map exhibited suggested very strongly that the Bardsey rocks had been subjected to at least two sets of earth-movement. To the earlier set might be referred the movements which crushed up the sedimentary series into shallow isoclinal

folds, packing them into kilted sheets, and often tearing the more brittle bands into discontinuous lenticles. Movements of this class had no recognized parallel among the Cambrian and Ordovician rocks of Carnarvonshire and Merionethshire. The effects of the later movements were traced most readily in the variations of the strike of the isoclinal structures. In this later movement the crumpled sheets prepared by the earlier movements had behaved as units, and as such had developed further folding and faulting, which, both in scale and in direction of trend, was not unlike the folding and faulting observed among the Ordovician rocks of the Snowdon syncline.

The record of a north-west to south-east flow of ice across Bardsey was interesting, and was a further justification of the view that the

> 'stiff clays with marine shells and boulders from the Lleyn . . . plastered to a height of 300 to 400 feet along the hills between Harlech and Barmouth,'

were due to ice encroaching from the Irish-Sea or Cardigan-Bay area eastwards on to the land.[1]

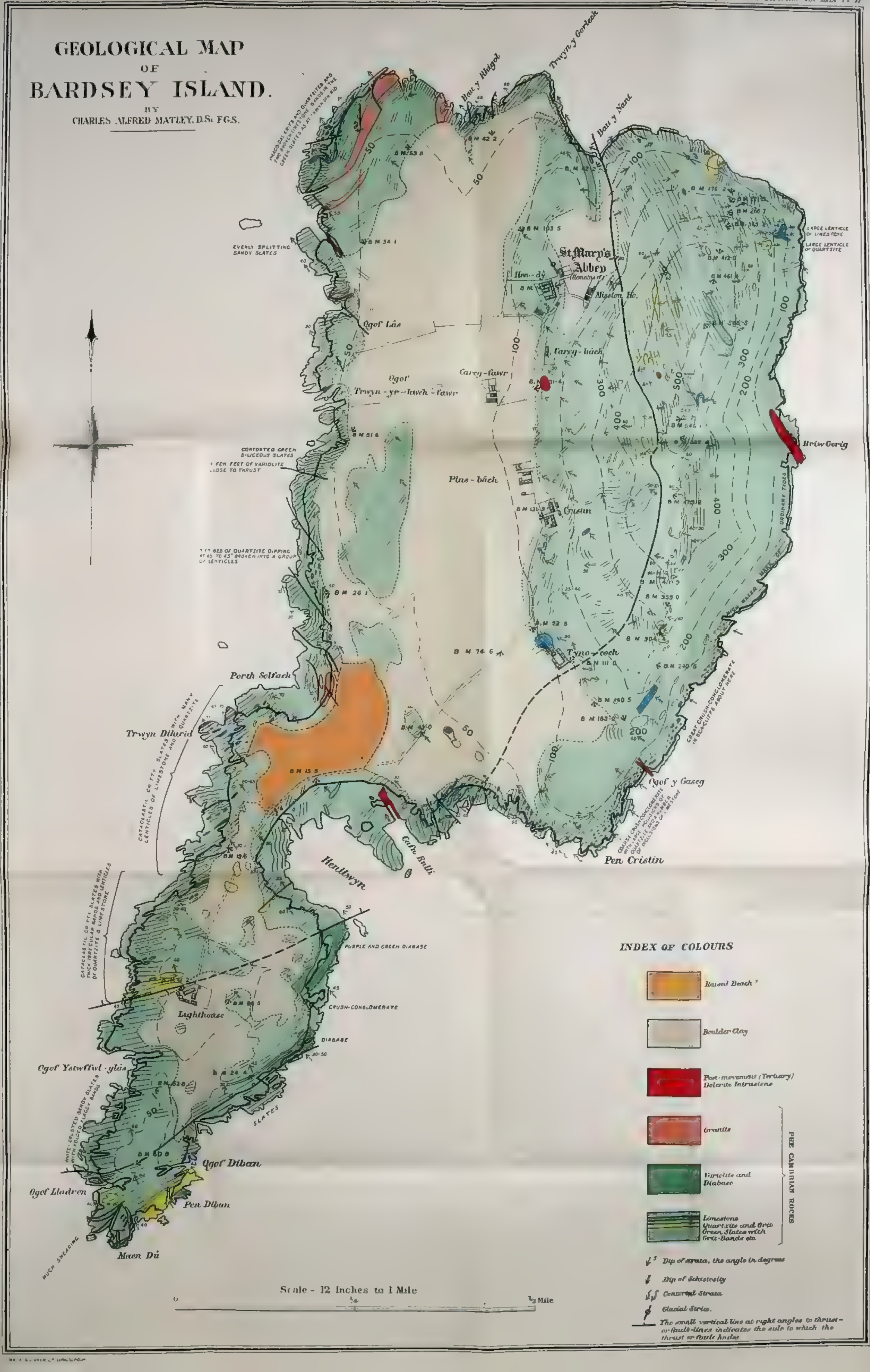
Dr. J. V. Elsden referred to the petrographical interest of the paper. The occurrence of post-movement olivine-dolerite dykes was especially noteworthy, as they had not hitherto been recognized, so far as the speaker knew, in the Lleyn district. It was true that certain intrusions—for instance, the Llanberis dykes, had been considered as being possibly of Tertiary age; but these contained no olivine, and could be shown to have been involved in the post-Bala movement. With regard to the folded sill of granitic composition, described in the paper, he would like to ask whether any difference in minute structure was recognizable in the two limbs of the fold. He would expect to find the eastern limb resembling an elvan rather than a granite.

Mr. G. W. Lamplugh commented on the similarity of the Bardsey rock-structures to those observed in the Isle of Man, and on the difficulty experienced in reconstructing the original arrangement from such shattered tangles. With regard to the glaciation, he reminded the Author that along the eastern coast of Ireland the ice pressed obliquely inland, so that ice from Ireland was not likely to have crossed to Wales as suggested.

Miss C. A. Raisin said that she had listened with especial interest to the paper, because it revived the recollections of some of her earlier geological work. She had hoped at that time to carry on the investigation, but work in other directions had prevented this. She rejoiced that the work was now being taken up, and expressed her appreciation of the detailed survey which the Author had begun to make. Her visit to Bardsey Island was short; but, from what she saw, it seemed clear that the structure was a continuation of that observed in the strip of country along

[1] See W. G. Fearnsides, 'Geology in the Field' Proc. Geol. Assoc. Jubilee Vol. (1910) pp. 822–23.


35
60


GEOLOGICAL MAP
OF
BARDSEY ISLAND.
BY
CHARLES ALFRED MATLEY, D.Sc. F.G.S.
St. Mary's Abbey
Carreg-fawr
Plas-bach
Cristin
Tyno-coch
Bau y Rhigol
Trwyn y Gorlech
Bau y Nant
Ogof Las
Briw Gerig
Porth Solfach
Trwyn Diliurid
Henllwyn
Ogof y Gaseg
Pen Cristin
Lighthouse
Ogof Ystwffwl-glas
Ogof Diban
Ogof Lladron
Pen Diban
Maen Du
EVENLY SPLITTING SANDY SLATES
CONTORTED GREEN SILICEOUS SLATES
LARGE LENTICLE OF LIMESTONE
LARGE LENTICLE OF QUARTZITE
PURPLE AND GREEN DIABASE
CRUSH-CONGLOMERATE
DIABASE
SLATES
MUCH SHEARING
ORDINARY TIDES
INDEX OF COLOURS
Raised Beach
Boulder Clay
Post-movement (Tertiary) Dolerite Intrusions
Granite
Variolite and Diabase
Limestone
Quartzite and Grit
Green Slates with Grit-Bands etc.
PRE-CAMBRIAN ROCKS
Dip of strata, the angle in degrees
Dip of Schistosity
Contorted Strata
Glacial Striæ.
The small vertical line at right angles to thrust- or fault-lines indicates the side to which the thrust or fault hades
Scale - 12 Inches to 1 Mile
0
½ Mile

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[No. 276 of the Quarterly Journal will be published next December.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

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Vol. LXIX. DECEMBER, 1913. No. 276.
Part 4.

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

[With Five Plates, illustrating Papers by Mr. J. Parkinson, Mr. L. F. Spath, and Mr. P. G. H. Boswell.]

Smithsonian Institution,
MAR 26 1914
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Session 1913–1914.

1914.

Wednesday,	January	21*
„	February (*Anniversary*, Friday, Feb. 20th)	4*—25*
„	March	11 —25*
„	April	8 —29*
„	May	13 —27*
„	June	10 —24*

[*Business will commence at Eight o' Clock precisely.*]

The asterisks denote the dates on which the Council will meet.

the south-west of the Lleyn. In that district the schistose structure, as emphasized by the Author, was very marked, and had affected rocks of different kinds. The specimens laid on the table from Bardsey Island could all be matched on the mainland. Doubtless this crush-zone had an interesting bearing on larger problems, as a previous speaker had pointed out.

The President (Dr. A. Strahan) remarked that the production of a map of Bardsey Island by the Author seemed likely to coincide with that of a map of Anglesey by Mr. Greenly: the two were likely to be mutually helpful, for those islands had much in common.

He enquired whether it was not a fact that the late Dr. Hicks had been the first to point out that the Irish-Sea ice had invaded the coast of Wales, owing to the sea-basin having been filled to overflowing, and that Dr. Jehu had confirmed this observation by his work in Pembrokeshire.

The Author thanked the President and Fellows for the kind way in which they had received his paper. He was glad to have the views of Mr. Barrow and Mr. Fearnsides on the nature and age of the earth-movements, although he himself had left the discussion of these questions until, on the completion of the mapping of the pre-Cambrian strip of the mainland, he would have the full field-evidence before him. He agreed with Mr. Fearnsides that soda-rocks occurred on the mainland, the sills intrusive into the Arenig of the Aberdaron district being albite-diabases.

To Dr. Elsden he replied that the post-movement dykes on the mainland seemed to be identical with those of Bardsey, and, although he had not yet examined any rock-slices of the former, he expected that many of them would prove to be olivine-dolerites.

It was a pleasure to see a former worker in Bardsey present on this occasion, and he paid a tribute to the value of Miss Raisin's work in that island and on the mainland, especially with regard to the igneous rocks.

In regard to the glaciology, he was sorry to have overlooked Mr. Fearnsides's record of a south-easterly ice-movement in Merionethshire. Much more would have to be done before the glaciation of South-Western Carnarvonshire could be regarded as fully understood. He had looked upon Dr. Jehu's discovery of boulders of Mourne-Mountain rocks in Pembrokeshire as evidence of radiation of ice from Ireland into Cardigan Bay, but, in view of Mr. Lamplugh's remarks, was now inclined to accept the latter's opinion that they came from the bed of the Irish Sea and not from Ireland itself.

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24. *On a* Group *of* Metamorphosed Sediments *situated between* Machakos *and* Lake Magadi *in* British East Africa. By John Parkinson, M.A., F.G.S. (Read June 11th, 1913.)

[Plate LI—Microscope-Sections.]

In the latter half of 1911, I had the opportunity of examining a group of crystalline rocks situated immediately below the southern edge of the great lava-plateau of the Kapiti Plains, and embracing many varieties of reconstructed sediments, from quartz-schists to highly crystalline marbles. Scattered outcrops of similar rocks have been described by Mr. Maufe from other localities in the Protectorate.[1] The rocks here described were found in approximately lat. 2° S. and long. 37° E., and, so far as I was able to follow them, form the ground drained by the headwaters of the Turoka River, a designation which I think might well be applied to the group, as the name is one of the few found on the usual maps of the district, and is likely in the future to become more widely known as an important station on the Magadi Branch Railway. The section to which I desire to draw attention is found on the right bank of a stream immediately south of the old 'safari' route to the Lake, about a couple of miles above the site of Turoka Station.

In apparent ascending order, the following rocks are met with:—

(1) At the base, a hornblende-schist, of which about 3 feet 5 inches is visible. A thin section of this rock shows large irregular plates of the common green hornblende, contained in a rather granular mosaic of water-clear plagioclase and quartz. The felspar is often untwinned, and commonly exhibits graduated zoning. In one part of the slide, diopside takes the place of the hornblende; sphene, apatite, zircon, and rarely a colourless idiomorphic epidote, are accessory minerals in a rock which calls for no special comment.

(2) This hornblende-schist is overlain by a flaggy and impure marble, 3 feet thick, and this in turn by

(3) A fine-grained biotite-gneiss, 2 feet thick.

This rock is of the 'pepper-and-salt' type, that is, a non-porphyritic rock, in which the black and white minerals are of small dimensions and approximately equal proportions. The biotite-flakes are about 1 mm. long, and constitute roughly a third to a half of the whole.

Unfortunately, this and the succeeding members of the section have been rendered so friable through weathering, that I found it impossible to procure a fragment from which a section could be

[1] See Colon. Rep. Miscell. No. Cd 3828, 1908, p. 29.

cut, and have accordingly had to rely on examples collected from the immediate vicinity.

(4) A calc-mica rock containing lenticles of biotite-gneiss, and 3 feet 8 inches thick. At first sight, the junction between Beds 3 and 4 appears to be sharply defined enough, but with a little care the two rocks can be seen to pass one into the other by the incoming of calcite-crystals in the underlying biotite-gneiss, segregated, moreover, into laminæ. These crystals, when thus gathered into streaks, are associated with hornblende, and form a passage-zone some 4 or 5 inches thick. A foot or so away, where the line of junction is more clearly defined, a lenticle of biotite-gneiss, about 3 inches long, is separated from the main bed of the underlying rock by a thin band of calcite crystals; while, higher up in the calc-rock, lenticles of the same type, an inch and a half thick, themselves containing thin streaks of calcite-crystals, are not uncommon. In addition to this, lenticles composed principally of hornblende, and about 10 inches long by half an inch thick, may be observed.

The remainder of the section calls for less comment.

(5) Hornblende-schist. A rock similar to No. 1. Thickness =1 foot.

(6) Impure calc-rock, 2 feet, containing quartz-felspar strings, having a direction parallel to the trend of the foliation, and, so far as could be observed, unconnected with any dyke-rock.

(7) Coarse quartz-felspar vein. Thickness=2 feet.

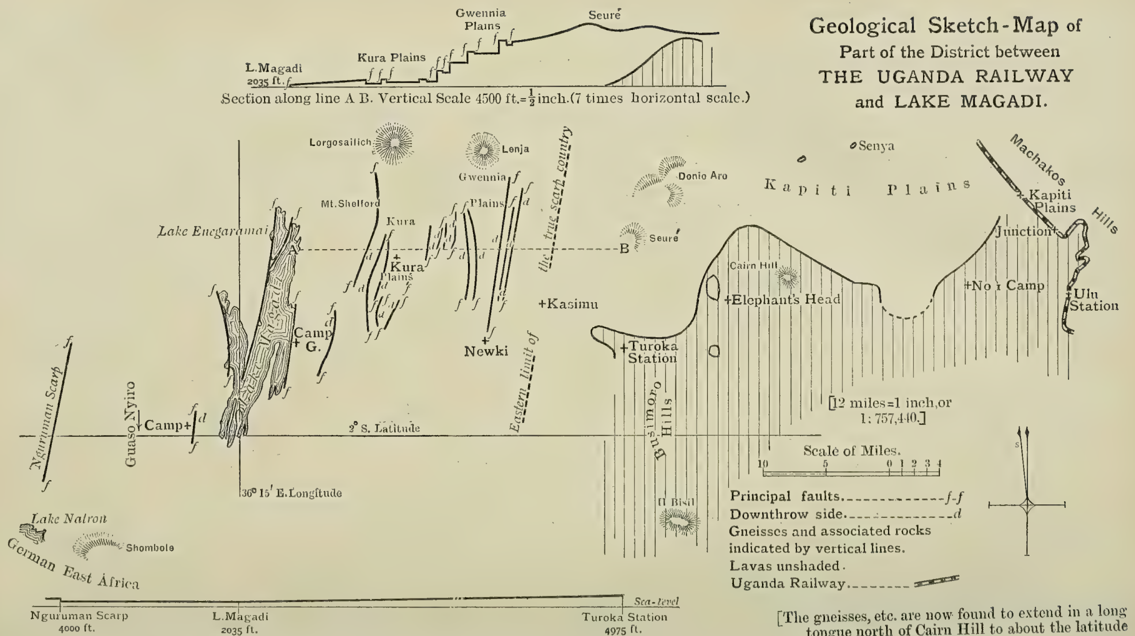
(8) Hornblende-schist. Thickness=2 feet.

(9) Impure calc-rock resembling No. 5, and about 4 feet thick, the top not being clearly seen.

From the foregoing facts I conclude that we have here a section of metamorphosed sediments, varying from an arenaceous to a calcareous type, and that a passage-zone between a calc-mica-rock and a biotite-gneiss does actually exist.

The relationship between a thin layer of the hornblende-schist and the common type of impure marble is shown in a specimen collected a few yards farther up the valley. A thin section shows on the one hand a hornblende-schist, with rare malacolite, on the other a coarse marble. The intermediate zone, 4 to 5 mm. wide, contains hornblende after malacolite, as also calcite and sphene, the latter in noticeable quantity, although both are greatly subordinate to the other two first-named minerals. In addition there is some water-clear plagioclase having small extinction-angles. Another instance of a similar association of hornblende-schist and marble was found in the same stream-bed, where a lamina 1 inch thick divides two calc-rocks. The former is a hornblende-schist, the hornblende being usually idiomorphic to the extent of showing prismatic and clinopinacoid faces, although the latter are often absent. Microcline and plagioclase, with low extinction-angles, are common, and there is much untwinned felspar and quartz. In regard to accessory minerals, sphene, zircon, and apatite

Geological Sketch-Map of Part of the District between THE UGANDA RAILWAY and LAKE MAGADI.



Section across the Rift Valley to show mean slopes. Vertical and horizontal scales the same. Length = 45 miles.

[The gneisses, etc. are now found to extend in a long tongue north of Cairn Hill to about the latitude of Senya.—*November 26th, 1913.*]

are not rare. A few irregular grains of calcite, presenting the appearance of an original mineral, are noteworthy.

With a view to the study of the arenaceous sediments, if they may be so termed, intercalated between the beds of marble, a thin section has been prepared of a rock which is almost entirely a binary compound of quartz and felspar. Its thickness was some 18 inches. The calc-rocks between which it was found were of different facies: the upper coarse, the lower much finer in grain. The rocks of the section were decomposed, and the section overgrown, but my impressions in the field were that the gneiss did not represent a sill. Most of the felspar is unstriped, but the rock contains a little acid plagioclase and microcline. Some secondary white mica, derived from felspar, and a few original flakes of a reddish-brown biotite, also occur. As appears to be usual in these rocks, the microcline is late in consolidation, and has corroded the other minerals. In this rock also the tendency of the quartz to form elongated vermicular phacoids and extremely irregular grains, with coral-like apophyses, is worthy of note. This structure appears to be characteristic of certain rocks of this series.

The same peculiarity is more marked in another example, also a binary compound of quartz and felspar, and found between marble beds in the stream known to the Masai as Il Bisil, south of the drainage-basin of the Turoka. The rock consists of an aggregate of quartz and felspar, with a few flakes of biotite and muscovite. The foliation is distinct, the quartz forms long grains which usually are transversely cracked, and suggest that the rock was originally a coarse grit- or pebble-bed. In some instances, the quartz-grains have been clearly formed before the microcline, the crystals of which abut against its surface. An acid plagioclase is an important constituent. The biotite has a marked absorption: C is brownish red, as in some kinzigites, and A is of a pale straw-colour.

Intercalated between marble beds from the same locality (Il Bisil) was collected another rock, having some relation with the kinzigites and with the last-described rock. It is composed of pink garnets, lapped about by a red-brown mica, in a base of quartz and water-clear felspar, the former predominating. The angles of extinction of the latter are small, but much of the felspar is untwinned. The quartz shows the elongated blunt-ended lenticles noticed before. Small granules of zircon also occur, and one or two of a mineral which appears to be the kyanite of other slides.

Similar rocks, having affinities with the kinzigites, were found in the stream-bed first mentioned, and about 300 yards from the recorded section.

The rock, a garnet-biotite-gneiss, contains some quantity of magnetite and ilmenite, the former being the commoner. The biotite is of the usual straw-coloured variety customary in these rocks, and quartz preponderates over felspar, the greater part of which is unstriped. There is no microcline. Zircon and apatite

are rare accessory minerals, and the rock contains also occasional grains of dirty epidote or sphene.

A rock with the same associates and from the same stream consists principally of scapolite, diopside, and brownish-red garnet with accessory calcite, quartz, hornblende, plagioclase, sphene, apatite, and zircon. The water-clear plagioclase belongs to the acid end of the series. The apparently corrosive action of the quartz and plagioclase on the hornblende is noteworthy, the last-named mineral giving finger-shaped cross-sections, which, it is of interest to see, are peripherally converted into glaucophane. This mineral has a pleochroism varying from yellowish-brown to ultramarine.

From the bed of an important tributary to the Turoka, entering below the streams above-mentioned, comes a compact gneiss containing epidote in quantity. The mineral forms irregular grains, and is occasionally idiomorphic. The scheme of pleochroism is, A, colourless, or very pale yellow; B, colourless; C, pale greenish-yellow. Sphene is a common accessory mineral, and is earlier in formation than the epidote. Quartz is abundant, and forms large grains containing many inclusions; apatite and zircon are rare. The acid plagioclase is often zoned, microcline is common, and corrodes the earlier plagioclase.

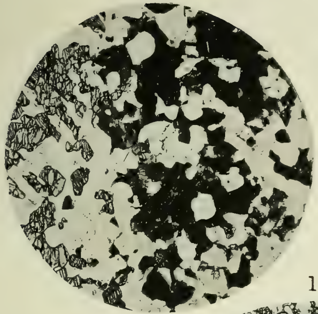
Three slides of kyanite-schist were cut from specimens representing three successive beds only a few inches apart, situated on the bank of one of the headwater streams of the Turoka. The uppermost is a kyanite-muscovite-biotite-quartz-schist with subsidiary microcline or microperthite. Quartz greatly predominates, the grains are elongated parallel to the predominant foliation, one grain polarizing over large and irregular areas, giving the impression of the slow rupture of viscous substance.

The underlying rock has a rather confused crystallization: microperthite is conspicuous, but there is no simply-twinned plagioclase. The quartz is dusty and full of inclusions, and the kyanite forms large irregular plates; a red-brown mica is conspicuous. White mica and zircon are accessory minerals.

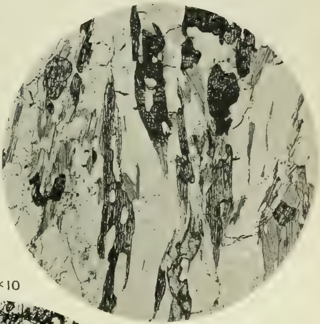
In the third section, muscovite and biotite are subordinate, the felspar has an irregular wavy extinction, suggesting very strongly fine microperthite; and, as before, there is no simple plagioclase. Locally, the kyanite is altering into a fine aggregate of hydrous white mica.

Elsewhere in the same stream-bed, kyanite-gneisses, still richer in the specific mineral, occur. A thin section of one shows the rock to consist almost entirely of kyanite and quartz, a few crystals of zircon and flakes of white mica being almost the only accessory minerals. The quartz shows slight signs of crush. The kyanite in these slides appeared to me in some respects abnormal, and I am much indebted to Mr. T. Crook, of the Imperial Institute, for checking my determination.

2. × 9

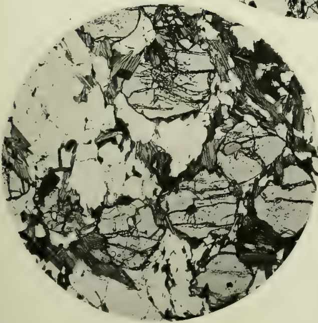


3. × 14

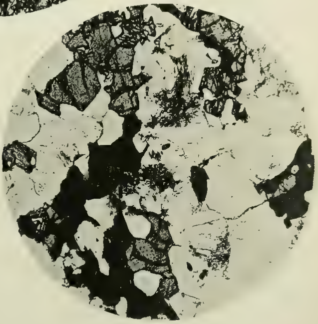


1. × 10

4. × 10



5. × 16



H. H. T. Photo.

Bemrose, Collo, Derby.

SCHISTS AND GNEISS FROM BRITISH EAST AFRICA.

Summary and Conclusions.

That part of British East Africa which borders on the Athi Plains, and extends westwards from Machakos up to the eastern edge of the Rift Valley, is an undulating country composed of foliated rocks of ancient appearance, among which biotite-gneisses are conspicuous. Pegmatite-veins cross the foliation, and are not associated with intrusive granites or dyke-rocks, so far as my observations go.

In the neighbourhood of the headwaters of the Turoka River, a group of altered sediments has been traced over an area of about 100 square miles, and these it is proposed to designate by the name of the Turoka Series.

A large number of rock-types are found, varying from one purely arenaceous, forming the locally conspicuous hills from which the majority of the headwater streams take their rise, to beds of marble of considerable thickness. Other varieties have been mentioned above, the most important being a series of kyanite-gneisses or schists and a scapolite-garnet rock. A river-bank section has also been described, showing the local succession and the passage, as I believe, between a calc-mica-rock and a biotite-gneiss.

Near the headwaters of the Turoka River, the dips of the planes of foliation of the various gneisses were consistently north-eastward or east-north-eastward.

For permission to publish these notes, I am indebted to the kindness of the Magadi Soda Company, to whom also my thanks are due for allowing much information, incorporated in the accompanying map (p. 536), to appear. The locations of the fault-scarps, the principal of which are shown, have been obtained from the Survey maps of the Magadi Branch Railway, produced under the direction of Mr. T. A. Ross, Resident Engineer, to whom I tender my thanks for much kindness and sympathetic help rendered while I was in East Africa. I am also greatly indebted to Mr. Herbert H. Thomas, Sec.G.S., for kindly preparing the microphotographs reproduced in the plate.

EXPLANATION OF PLATE LI.

Fig. 1. Section showing the relationship of the hornblende-schist to the common type of impure marble. The hornblende-schist is shown on the extreme left, and the marble on the right. The intermediate zone is mainly composed of hornblende after malacolite, calcite, and sphene. Ordinary light. Magnified 10 diameters.

2. Hornblende-schist. The photograph shows irregular plates of common green hornblende, locally replaced by almost colourless diopside, in a clear granular mosaic of plagioclase and quartz. Ordinary light. Magnified 9 diameters.

3. Kyanite-schist. The rock consists of kyanite, muscovite, biotite, and quartz, with subsidiary microcline. The grains are elongated parallel to the direction of foliation. Ordinary light. Magnified 14 diameters.

4. Garnet-schist related to the kinzigites. The section shows pink garnets lapped about by a red-brown mica, and set in a base of clear felspar and quartz. Ordinary light. Magnified 10 diameters.

5. Epidote-hornblende-gneiss. The rock consists of yellowish epidote and dark-green hornblende, often closely associated, in a matrix of quartz and felspar. Sphene is a common accessory. Ordinary light. Magnified 16 diameters.

25. *On* Jurassic Ammonites *from* Jebel Zaghuan (Tunisia). By Leonard Frank Spath, B.Sc., F.G.S. (Read March 5th, 1913.)

[Plates LII & LIII.]

Contents.

I. Introductory Remarks.

The fossils described in the following pages were collected on a hurried excursion to the mountain of Zaghuan, the graceful, sharp-peaked summit of which is a prominent landmark that greets the eyes of travellers in the Regency of Tunis. Apart from being the most conspicuous mountain in the country—though inferior in absolute height to Jebel Chambi,—Zaghuan also forms the most important elevation of the Tunisian Atlas from a geological point of view, and the tectonic problems which it suggests are manifold and of exceeding interest. Without discussing these, it may suffice to mention that the late Dr. Pervinquière in 1903[1] summarized the existing geological knowledge of the mountain as follows:

'Massive limestones of Liassic age form the principal mass of the mountain, whereas the Oxfordian and Tithonian play but a subordinate part in its constitution.'

As a matter of fact, the 'Oxfordian' fossils of Pervinquière characterize the zone of *Peltoceras transversarium*, which corresponds approximately with what was at one time called in this country the zone of *Aspidoceras perarmatum*. On the other hand, he mentions Kimmeridgian forms, but includes them in the Tithonian.

A later work by the same author[2] is devoted entirely to Tunisian cephalopods. Very few of the ammonites are of Jurassic age, however, and of these only about ten come from Jebel Zaghuan, none from the pre-Corallian deposits. Several other works on the geology of Tunis have been published since; but, so far as I am aware, no new facts regarding the mountain have come to light. I offer the following notes, therefore, in the hope that they may be of general interest; for the study of the ammonites has revealed

[1] 'Étude Géologique de la Tunisie Centrale' Paris, 1903, p. 253: 'Djebel Zaghouan.'

[2] 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' Text & atlas, Paris, 1907.

a few interesting facts, despite the circumstance that the small collection consists of casts and impressions which are not in a very good state of preservation. In consequence, specific determination has proved tedious, and, so far as some worn Upper Jurassic specimens are concerned, too unsatisfactory to warrant the expression of an emphatic opinion. But the observations modify the current opinion, insomuch as there is now good evidence in favour of the presence of the zone of *Reineckeia anceps*, hitherto believed to be absent, with all the other strata intervening between the Middle Lias and the Corallian. Domerian (that is, Middle Liassic) ammonites are also recorded for the first time, and the discovery of a rich cephalopod fauna of Argovian age throws interesting light on certain ammonites described by previous authors as of Lower Tithonian age.

It is a matter for regret that further stratigraphical observations or visits to the locality were impossible.

II. The Jurassic Rocks of Jebel Zaghuan and their Cephalopod Fauna.

(1) The Lias.

The Lias is represented at Zaghuan by thick, massive, bluish-grey limestones of confused stratification. The base is unknown, and it is impossible to say at present which are the oldest beds represented. The late Prof. Baltzer[1] had collected a number of Liassic ammonites in 1893, and the list compiled with the help of Prof. Mayer-Eymar, and published in 1895,[2] included (besides belemnites and lamellibranchs) forms of the following Lower Liassic genera: *Vermiceras* [*Arietites*], *Coroniceras* [*Arietites*], *Arnioceras* [*Arietites*], *Arietites*, *Deroceras* [*Ægoceras*], *Androgynoceras* [*Ægoceras*], *Platypleuroceras* [*Ægoceras*]; and also the Toarcian *Dactylioceras* [*Cœloceras*] *anguinum* (Rein.).

They are the only Liassic ammonites that have ever been recorded from Zaghuan (and, indeed, from the whole of Tunisia), and were collected below the ridge near the Col de Bourzen, partly among the screes. The matrix is not the same in all the specimens, and the curious mixture of Lower, Middle (to French geologists), and Upper Liassic forms seems to have made both Dr. Pervinquière and Prof. Haug somewhat sceptical about the identifications. The former[3] records only little-determinable belemnites and *Terebratulæ* from these limestones; but M. Ficheur and Prof. Haug[4] found, besides belemnites 'of the *acuti* group,' '*Pygope*' *aspasia* Meneghini (Von Buch), a brachiopod common to

[1] 'Beiträge zur Kenntniss des Tunisischen Atlas' N. Jahrb. vol. ii (1893) pp. 26–41.
[2] *Id. ibid.* vol. i (1895) pp. 105–106.
[3] 'Étude Géologique de la Tunisie Centrale' 1903, p. 29.
[4] C. R. Acad. Sci. Paris, vol. cxxii (1896) p. 1354.

the Alpine, Italian, and Sicilian Domerian.[1] Prof. Haug[2] therefore classed the beds in the Middle Lias, and stated that the Toarcian seemed to be absent in Tunisia.

I have not been able to find Lower Liassic ammonites; but my search among the screes and rocks between the Col de Bourzen and the summit-ridge was of a superficial nature, since I did not recognize the locality at the time. I was fortunate enough, however, to collect the following Domerian forms in loose débris by the side of the path to the Poste Optique (975 metres) just before that path reaches the final slope: that is, at a height of about 900 metres:—

Protogrammoceras cornacaldense Tausch, var. *zeugitanum*, nov.
Pr. aff. *costicillatum* (Fucini), var. *detractum* Fucini.
Pr. sp. nov.
['*Lioceras*'] gen. et sp. nov. aff. *grecoi* (Fuc.).

Together with these specimens was found a fragment of an ammonite similar as to matrix and mode of preservation, which strikingly resembles the well-known *Harpoceras bicarinatum* Ziet. *non* Münster sp. (=*cumulatum* Hyatt). On account, however, of its association with Domerian fossils, I am inclined to think that my specimen is a heterochronous homœomorph of that *Harpoceras*, rather than that the latter appeared earlier in Tunis than it did in Europe, where it seems to be unknown in the lowest zones of the Toarcian. In either case, the evidence in favour of the presence of the Toarcian afforded by this fragment, which shows neither umbilicus nor suture-line, is most unsatisfactory[3]; and, further, it is possible that the above-cited *Dactylioceras anguinum* (Rein.), collected by Prof. Baltzer, may really be one of the many similar Domerian 'Cœlocerates' recently described from Italian deposits. Hence the Mesoliassic character of at least the main mass of the grey limestones would remain established; whereas better evidence would be required in confirmation of the presence of the Toarcian.

[1] The term Domerian is here used in Bonarelli's sense, that is, to denote the Upper Pliensbachian (Upper 'Charmouthian' in Bonarelli), which corresponds with what the Officers of the Geological Survey call the Middle Lias: namely, the zones of *Amaltheus margaritatus* and of *Paltopleuroceras spinatum*. Mr. Buckman (in 'Yorkshire Type-Ammonites') also uses the term Domerian for this stage, but he restricts the term Charmouthian to Bonarelli's Lower Charmouthian. Mr. W. D. Lang (in Geol. Mag. dec. 5, vol. x, 1913, p. 401) introduces the term Carixian for the Lower Pliensbachian (which latter has priority before Charmouthian, Liasian not being acceptable): that is, for the zones from *Echioceras raricostatum* below, up to, and including, that of *Ægoceras capricornus*. The new term deserves general acceptance, since it enables us to keep the term Pliensbachian for the whole, with its original connotation. The incoming of *Seguenziceras* and other Hildocerates at the base of the Domerian (zone of *Seguenziceras algovianum* of Buckman), together with the appearance of Amaltheids and the almost complete extinction of the Liparoceratidæ, is the most important palæontological characteristic.

[2] 'Traité de Géologie' vol. ii (1908) pt. 2, p. 987.

[3] See also under specific descriptions.

(2) The Callovian.

Reineckeia anceps (Rein.) and *Lunuloceras lunula* (Ziet.) have been recorded from Batna in Algeria; and a specimen of a *Reineckeia* comparable with the type-form, or, in any case, belonging to the '*substeinmanni*' group of Lemoine,[1] from Foum Islamen, Constantine, is in the British Museum (Natural History).[2] But it was generally believed that the whole series of beds from the Domerian to the Argovian was absent in Northern Tunisia. I have, however, found the two forms mentioned below on the path to the Poste Optique, about half way up, where a branch of it leads into a small pit of red limestone, evidently used for getting material to repair the path. The outcrop is small, much overgrown, and obviously forms quite an isolated patch amid unfossiliferous grey limestone of different age. The matrix (red marble) is the same as that of the specimen from Foum Islamen, and both my specimens were cut out of the rock-surface. They are *Reineckeia* aff. *hungarica* Till and *Perisphinctes* cf. *bieniaszi* Teisseyre.

Both forms belong to the zone of *Reineckeia anceps*, and the world-wide distribution of the genus *Reineckeia* in deposits of Callovian age has long been proved.

(3) The Corallian.

The lower part of the Corallian, as interpreted by Mr. Buckman[3] (that is, the *cordatus* and *precordatus* zones), as also the upper zones of the Divesian (Oxfordian) seem to be absent; but the Argovian, or zone of *Peltoceras transversarium*, is well represented. Pervinquière quotes only *Phylloceras manfredi* Opp., *Sowerbyceras tortisulcatum* (d'Orb.), and *Ochetoceras arolicum* (Opp.) with unidentified Phyllocerates, *Perisphinctes*, and *Aspidoceras* from a small outcrop of greenish-grey limestone on the Télégraphe. But G. Le Mesle[4] also found (perhaps at the same spot):—

Lytoceras liebigi Opp.
Taramelliceras [*Oppelia*] *anar* (Opp.).
Taramelliceras [*Oppelia*] cf. *bachianum* (Opp.).
Peltoceras transversarium (Quenst.).
Perisphinctes (Biplices) cf. *kobelti* Neum.

Whereas Baltzer records from the south of the mountain, near the 'Gabrielle' mine:—

Taramelliceras [*Oppelia*] *callicerum* (Opp.).
Taramelliceras [*Oppelia*] *flexuosum* (Münst.).
Aspidoceras ægir (Opp.).
Peltoceras eugenii (Rasp.).
Perisphinctes plicatilis (Sow.).
Perisphinctes martelli (Opp.).
Simoceras [*Perisphinctes*] *doublieri* (d'Orb.).

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[1] P. Lemoine, 'Pal. Madagascar: pt. 8—Ammonites Jurass. Supér. d'Analalava' Ann. Paléont. vol. v (1910) p. 9 [145].

[2] Specimen No. C 10568.

[3] See G. W. Lamplugh & F. L. Kitchin, 'On the Mesozoic Rocks in some of the Coal-Explorations in Kent' Mem. Geol. Surv. 1911, p. 132.

[4] 'Sur le Jurassique du Zaghouan' Bull. Soc. Géol. France, ser. 3, vol. xvii (1888) p. 63.

At a locality which may be that marked 'Bou Goubrine' in fig. 1 of Baltzer's pl. iii,[1] I collected a large number of ammonites preserved in red limestone. Most of them had weathered out of the rock, and lay loose at the surface, which was overgrown with brushwood to such an extent that the relations of the outcrop could not be traced clearly. The forms are:

Phylloceras cf. *mediterraneum* Neum.
Phylloceras cf. *subptychoicum* Dacqué.
Phylloceras manfredi (Oppel).
Phylloceras cf. *saxonicum* Neumayr.
Phylloceras cf. *isotypum* Benecke.
Sowerbyceras protortisulcatum (Pompeckj).
Sowerbyceras cf. *loryi* (Mun.-Chalmas).
Lytoceras cf. *gastaldii* Gemmellaro.
Lytoceras aff. *polycyclum* Neumayr.
Ochetoceras arolicum (Oppel).
Ochetoceras canaliculatum (Münst.).
Ochetoceras sp.
Taramelliceras cf. *anar* (Oppel).
'*Lissoceras*' *erato* (d'Orb.).
Perisphinctes (Grossouvria) cf. *regalmicensis* Gemm.
Perisphinctes (Grossouvria) cf. *navillei* Favre.
Perisphinctes (Grossouvria) cf. *densicosta* Gemm.
Perisphinctes (Biplices) kobelti Neum.
Perisphinctes (Ataxioceras) æneas Gemm.
Perisphinctes (Ataxioceras) cf. *michalskii* Buk.
Perisphinctes (Ataxioceras) cf. *depereti* de Riaz.
Perisphinctes (sensu stricto) cf. *sayni* de Riaz.
Perisphinctes (do.) cf. *jelskii* Siem.
Perisphinctes (do.) *plicatilis* de Riaz, *non* Sow., *nec* Siem.
Perisphinctes (do.) cf. *convolutus* (Quenst.).
Perisphinctes (do.) sp. nov. aff. *trichoplocus* Gemm.
Peltoceras toucasianum (d'Orb.).
Peltoceras cf. *toucasianum* (d'Orb.).
Peltoceras pervinquieri, nom. nov. mihi = *fouquéi* Pervinq. *non* Kil.
Peltoceras aff. *fouquéi* Kil.
Aspidoceras cf. *ægir* (Opp.).

There is perfect similarity of matrix in all the specimens: the outcrop consists of a truly Alpine, ammonitic 'Knollenkalk,' which contains apparently no other organisms; but the list includes forms from the *transversarium* zone mixed with some from the *acanthicus* beds. If we call to mind the curious fact that, not only in the Southern Alps, but also in Sicily there is a great development of the Argovian to the exclusion of the higher beds of the Corallian, followed without any apparent break by the *acanthicus* beds, it appears quite probable that the two 'zones' occur here in a similar manner, and that the apparent mixture is not due to doubtful identifications.

Most of the forms enumerated above are of undoubted Argovian age. With regard to the remainder, a brief discussion of their stratigraphical value may be desirable.

Peltoceras fouquéi Pervinq. *non* Kil. seems to be the only form that had previously been recorded from this locality or its vicinity. The matrix also is a red limestone, and Aubert collected it 'près de la zaouia de Sidi Bou Goubrine.' Pervinquière originally gave the age of the ammonite as Sequanian,[2] but in 1907 he figured it as a Lower Tithonian form. The latter age seemed to him 'more probable, especially as nothing else indicates the occurrence

[1] Neues Jahrb. vol. ii (1893).
[2] 'Étude Géologique de la Tunisie Centrale' 1903, p. 28.

of the lower beds at that locality.' This does not apply now, however.

Peltoceras fouquéi Kil. occurs in Algeria, together with *transversarium*-zone ammonites; but the type comes from Andalusian beds of probably a higher horizon, and several authors record it from the Lower Tithonian. The evidence afforded by this form, therefore, is not satisfactory.

Perisphinctes (Biplices) kobelti Neum. is another ammonite figured and described by Pervinquière as a Lower Tithonian form. Neumayr[1] stated that the horizon was not directly known; but he thought that, judging by the general appearance of the ammonite, it undoubtedly belonged to the upper regions of the Upper Jurassic. The matrix is a red limestone, identical with the *Diphya* Kalk of the Southern Alps, and the type-specimen was collected by Dr. Kobelt rather high up on the northern slope of Jebel Zaghuan, at a spot where ammonites of fair size were abundant. It is impossible to say whether this refers to some locality on the Poste Optique, other than the greenish-grey limestone outcrop mentioned by Pervinquière — as at Bu Gubrîn, where similar red marble occurs, all the seventy specimens that I collected were of small dimensions. Le Mesle, as we have seen above, cited this form together with *Peltoceras transversarium*; a statement which caused Pervinquière to point out that Le Mesle, as well as Baltzer, had certainly mixed up 'Oxfordian' and Tithonian. The Tithonian age of this form, as well as of *Peltoceras fouquéi* Kil., seems by no means proved, however, and Pervinquière, who lays much stress on the resemblance of the red marble matrix with his Lower Tithonian limestone from Jebel Ben Saidan, 'known to belong without doubt to the beginning of the Tithonian,' has himself been misled. It is well to remember here that Pervinquière includes Upper Kimmeridgian (that is, the old '*acanthicus*-zone') forms in his Lower Tithonian.

Perisphinctes simoceroides Font. is another ammonite, figured and described by Pervinquière as probably of Lower Tithonian age, although the specimen came from the greenish-grey 'Oxfordian' limestone of the Poste Optique. It is possible, as that writer thinks, that the form the type of which comes from the *tenuilobatus* beds of Crussol appeared earlier in Tunis; but the identification may also be at fault, for Pervinquière says:

> 'at any rate, the ammonite can be more closely attached to *simoceroides* than to the "Oxfordian" species *sutneri* Choff. or *trichoplocus* Gemm.'

The evidence afforded by those Phyllocerates and Lytocerates which are of '*acanthicus*' age is equally unsatisfactory. The specimens are imperfect casts, and it will be necessary to mention in the specific descriptions that some of the identifications are doubtful. The same may be said of *Sowerbyceras loryi* (Mun.-Chalm.). That form—or, at least, two closely-allied, non-constricted

[1] 'Geogr. Verbr. d. Juraform.' Denkschr. K. Akad. Wissensch. Wien, vol. l (1885) p. 139.

ammonites, the dimensions of which agree fairly well with the type—occurred together with a very large number of specimens of *Sowerbyceras protortisulcatum* (Pomp.), and although *S. loryi* has been quoted from various horizons, it certainly occurs in beds higher than the Argovian. Yet Pervinquière mentions already [1] the singularly close resemblance of one of his fragments to *S. loryi*, although Munier-Chalmas was of opinion that the specimens (associated with *Ochetoceras arolicum* Opp. sp. and other Argovian ammonites) belonged to *S. tortisulcatum*. As Pervinquière says, the two forms are indeed closely allied; and, since the differences do not seem so constant as has been made out, there will often be great difficulty in the distinction. This case, then, is similar to that of *Peltoceras fouquéi* Pervinq. *non* Kil., which is found with the older *P. toucasianum* and *P. transversarium* and an intermediate form.

It may be added that Pervinquière mentions also a true *Sowerbyceras loryi* from Zaghuan; but the evidence, like that of *Simoceras* cf. *doublieri* (d'Orb.),[2] a doubtful impression in red limestone, does not appear strong enough to warrant the attribution of these forms to the Lower Tithonian with certainty. Until the relations have been more clearly determined, the presence of the '*acanthicus*' beds, which would include both the Upper Kimmeridgian and the Lower Tithonian, cannot be considered as proved beyond doubt. Their presence is quite probable, since, on the neighbouring Jebel Ben Saidan, similar red limestones with undoubted '*acanthicus*' forms occur; but it should be pointed out that the distinction between the so-called 'Lower Tithonian' and the Argovian is a matter of great difficulty with the material that is at present at our disposal.

(4) Conclusions.

The absence in the Tunisian Atlas of all strata intervening between the Middle Lias and the Argovian has generally been regarded as an established fact. The presence of the Callovian, however, necessitates some modification of that view. The Middle Jurassic transgression began in Callovian times, since deposits of that age probably rest directly on the Domerian. The latter has now yielded typical ammonites, but the question as to whether the Toarcian is completely absent must remain undecided.

Whether the higher beds of the 'Oxfordian' are represented or have, perhaps, been cut out by the extensive faulting, of which the general calamitization seems to afford proof, so that the Middle Oolitic succession may be more complete than we think, or whether new transgressions in Argovian and Upper Kimmeridgian times brought back the sea and exactly similar deposits of red ammonitic limestones, it is impossible to say at present.

The *Ellipsactinia* Limestones which have been recorded from

[1] 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' (1907) p. 15.

[2] *Ibid.* p. 29.

Jebel Zaghuan appear to indicate the incoming of a different facies at the top of the Jurassic System.

It remains only for me to acknowledge very gratefully my indebtedness to the officials of the Geological Department of the British Museum (Natural History) for facilities afforded during the examination of the specimens in their charge; and to express my great obligation to Dr. A. Morley Davies and Mr. C. P. Chatwin, for kindly looking through this paper and offering valuable suggestions.

III. Description of the Ammonites.

(1) LIAS.

Family **Hildoceratidæ** Hyatt *em.* S. Buckman.

Protogrammoceras, gen. nov.

A brief explanation is necessary in justification of the establishment of this new genus.

The present state of the classification of the Domerian Hildoceratidæ is unsatisfactory. Most authors either group the forms which are here considered with ammonites of later lineages, but similar external appearance, or else refer them to the convenient though much-abused genus *Harpoceras*, *sensu latissimo.*

A few examples may be mentioned. Prof. Haug[1] quotes the typical rectiradiate Domerian *Seguenziceras algovianum* (Opp.) alternately as *Grammoceras* and *Harpoceras*, which, in turn, also are used to accommodate A. d'Orbigny's *Ammonites normanianus.* A. Fucini,[2] again, places the latter in *Hildoceras*, also a strictly Toarcian genus; and P. Rosenberg[3] restricts the genus *Harpoceras* to forms with a carinatisulcate periphery, although that genus had already been restricted by Mr. Buckman to the true Toarcian *falciferi* twenty-two years earlier.[4] On the other hand, Dr. Rosenberg identified a Middle Liassic sickle-ribbed form with *Grammoceras fallaciosum* Bayle from the *jurense* zone, whereas it is not difficult to see that Bayle's excellent figure[5] is distinguished by a particular straightness of the costæ on the lateral area.

The present desideratum is a genus in which to place the ammonites collected at Zaghuan. Unfortunately, the material is very scanty, and even in the British Museum collections Mesoliassic Hildoceratidæ are almost unrepresented, wherefore an original study of the sutures, inner whorls, and probable septate character of the carina could not be carried out. On the other hand, it is not

[1] 'Traité de Géologie' vol. ii (1908) pt. 2.

[2] 'Cefalop. Liass. del Mte. di Cetona' pt. 5, Pal. Ital. vol. xi (1905) p. 108.

[3] 'Liasische Cephal.-Fauna d. Kratzalpe' Beitr. Paläont. & Geol. Œsterr.-Ung. vol. xxii (1909) p. 304.

[4] Geol. Mag. dec. 3, vol. iv (1887) p. 397.

[5] 'Expl. Carte Géol. France' vol. iv (1878) pl. lxxviii, figs. 1 & 2.

desirable to propose a more detailed classification of these forms, when one has to rely largely on the published descriptions of previous authors. I will indicate, therefore, only a few groups into which the ammonites in question might be collected within the genera *Seguenziceras* Levi (=*Arieticeras* Seguenza) and *Protogrammoceras*, nov. Further subdivision will doubtless be necessary as our knowledge of these forms grows.

The classification is based on the course of the radial line, in the first place, as the most constant feature of the shells. Mr. S. S. Buckman has shown how it may well be used, in conjunction with the suture-line, as a basis for classification [1] in the Hildoceratidæ in any case. Objections on account of the change in the radial line on the same ammonite will hardly be raised. Such changes do occur, not only in Hildoceratidæ (notably, for example, in certain *Ludwigellæ*), but also in many other families ('Polymorphidæ': *Fontannesia*; Oppelidæ: '*Haploceras*,' etc.). They are always limited to, at most, the last 30° in circular measure of the body-chamber, leading up to the mouth-border, and can easily be distinguished. By far the greater part of the body-chamber and the previous whorls have, for all practical purposes, an identical radial curve. It is interesting to note here that, even in cases where the irregular development of the ornament is said to be very striking, as in *Indoceras baluchistanense* Nœtling, [2] the sigmoidal course of the radial line is really fixed, and it seems that only the change in its character (from striate to costate) follows no law.

With regard to the suture-line, I am fully aware of the difficulties attending the proposed classification. The sutures of these early forms are too similar in general outline to have received much attention in the past, and they are, therefore, but imperfectly known. We now know, however, that in some striking cases an identical radial line may be combined with a notable difference in the suture-line, and I am quite unable to endorse Dr. Rosenberg's view. That author, [3] after studying well-preserved material, refrained from giving detailed descriptions and figures of the sutures of his 'Harpocerates' because 'they offer no or only very slight distinctions for specific separation.' In fact, a comparison of the sutures given by Dr. Fucini [4] for his various forms of '*Harpoceras*,' '*Grammoceras*,' and '*Hildoceras*,' seems to show that they differ more in 'species' of the same genus than they do in certain 'species' of different genera. But this merely emphasizes the undesirability of adopting Fucini's classification. He deems it impossible to separate the varieties *costicillatum* and *inseparabile* of

[1] 'Inferior Oolite Ammonites: pt. 10—Supplement' Monogr. Pal. Soc. vol. lii (1898) pp. i & ii.

[2] F. Nœtling, 'Die Entwicklung von *Indoceras baluchistanense* Nœtlg.' Geol. & Palæontol. Abhandl. (Jena) n. s. vol. viii (1906) pt. 1.

[3] 'Liasische Cephal.-Fauna der Kratzalpe' 1909, p. 288.

[4] 'Ammoniti del Lias Medio dell' Appennino Centrale' Pal. Ital. vol. vi (1900–1901) pp. 17–65 & text-figs. 24–48.

d'Orbigny's *normanianum* from the type, merely on account of the section, which is quadrate in the former two and acute in the latter—and I quite agree with him there. In my proposed classification they would also be united, assuming, of course, that there is agreement in the radial curve of the three forms: since the rather bad figures do not let this character come out very clearly. Our belief in the close affinity of these forms receives a shock, however, when we compare the sutures of, for instance, the var. *costicillatum* of '*Grammoceras*' *normanianum* (d'Orb.)[1] with that of its subvariety *detractum*, and find that there are marked differences. The former has an unsymmetrically-bifid external lobe, and a wide external saddle with a quadrate, bifid, inner branch. The second lateral saddle is also bifid, the first auxiliary lobe wide and low. In the latter variety, on the other hand, the lateral lobe is regularly trifid and the external saddle narrower, with a slender, monophylloid, internal branch; a similar, narrow, monophylloid, second lateral saddle is present, and there is also a strong forward inclination of the rest of the suture.

All this clearly shows the need for a revision of these forms, whenever more observations and material are at our disposal.

It is scarcely necessary to add now that the classifications of those Continental authors who consider the radial line variable, and in the absence of suitable sutures base them on the outward shape of the conch only, opposing forms with a carinatisulcate venter to those of oval-lanceolate section and an angular periphery, seem to me unjustifiable. A study of the inner whorls of some of the forms belonging to the lineages here considered has shown the anagenetic character of the periphery, from fastigate to carinate and subsulcate and then to carinatisulcate; and, if we were to be guided solely by that criterion in our classification, we might possibly refer several fragments of the same ammonite to three different genera. Of course, as Württemberger[2] pointed out more than thirty years ago, this difficulty applies equally to many other groups now accepted universally; and it could be argued that the radial line also (or, indeed, even the suture) does not help us in the distinction of the ill-characterized inner whorls. But it is maintained here that, although there are transitions in the radial line, we shall generally be able to group together forms of close genetic relations; whereas, in each of the several groups distinguished by different radial curves, we find produced forms with, for example, a carinatisulcate venter—they are only morphological equivalents, and cannot be classed together. A striking example is afforded by pl. ix of Fucini's work (already cited) on the Cephalopoda of the Central Apennines. Here, on account of a common acute venter, a number of forms are united as 'Grammocerates,' including '*Grammoceras*' *subtile* Fuc. (fig. 10), probably a derivative of the

[1] A. Fucini, 'Amm. del Lias Medio dell' App. Centr.' p. 30 & figs. 29–30.

[2] 'Studien über die Stammesgeschichte der Ammoniten' Darwinistische Schriften, No. 5, Leipzig, 1880.

true recticostate Seguenzicerates, whose generic difference will be admitted readily by most palæontologists.

Many of the ammonites in question occur in the Middle Lias of Italy, and a great number of forms are founded on imperfect specimens, the figures of which are of as much value as those of the older authors, who paid so little attention to the course of the radial line. For instance, the true curve of the ornament is very doubtful in A. d'Orbigny's *Ammonites normanianus*[1] or in '*Harpoceras antiquum*' Wright,[2] and I question the correctness in the former, because of the unusual character of the curve clearly shown in a tracing; the latter form, which, I may mention, does not seem to have been rediscovered and is quoted by its author from the *jamesoni* zone (!), is represented in three widely differing drawings. The type-specimens are not in the British Museum collection. Finally, the grouping under '*Harpoceras*' *boscense* Reynès of forms of such widely differing appearance as those figured by Meneghini, Zittel, Geyer, and others, has caused a great deal of confusion.

The radial curve, then, enables us to separate the Middle Liassic Hildoceratidæ into Rectiradiata and Flexiradiata. The former belong to the genus *Seguenziceras* Levi (=*Arieticeras* Seguenza); but the definition given by Zittel[3] will have to be altered, so as to include also forms with a narrow umbilicus and a more compressed section, having simply a carinate venter. Some of the very evolute forms are apparently transitional to Lower Liassic Polymorphids. By far the greater number of the ammonites belonging to the genus *Seguenziceras*, including the type, are subrecticostate; but there are lateral branches developing truly recticostate and rursiradiate forms respectively.

The flexiradiate forms are here united in the one genus *Protogrammoceras*, but belong to two separate divisions: one being distinguished by increasing peripheral projection, and giving rise to subfalciradiate and falciradiate forms; the other, where there is reduction in the peripheral projection, develops subanguliradiate and angulirursiradiate forms. They may, then, be arranged as follows:—

- Genus *Seguenziceras* ......
  - Rectiradiata: example *bertrandi* (Kil.).
  - Subrectiradiata: example *algovianum* (Opp.).
  - Rursiradiata: example *retrorsicosta* (Opp.).
- Genus *Protogrammoceras*.
  - Increase in projection.
    - Subfalciradiata: example *antiquum* Geyer *non* Wright.
    - Falciradiata: example *celebratum* Fuc.
  - Decrease in projection.
    - Subanguliradiata: example *normanianum* Fuc. *non* d'Orb.
    - Angulirursiradiata: example *lavinianum* Mgh., especially var. *retroflexum* Fuc.

[1] 'Pal. Française: Terr. Jurass.—Céphalopodes' vol. i (1842–49) pl. lxxxviii & p. 291.

[2] 'Lias Ammonites' Monogr. Pal. Soc. (1878–86) pl. lvii, figs. 1–4 & p. 431.

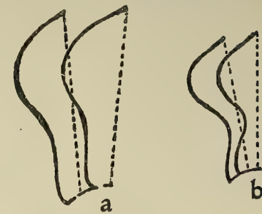
[3] 'Grundzüge der Paläontologie' vol. i (1910) p. 487 (under *Arieticeras*).

Figs. 1–4 *illustrate typical radial lines belonging to the four groups.*

Fig. 1.—*Subfalciradiate.*

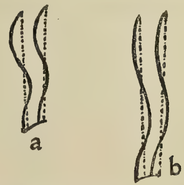
[‘*Harpoceras*’ *antiquum* Wright, in Geyer, ‘Hinter-Schafberg’ 1893, pl. ii, fig. 8 *a*.]

Fig. 2.—*Falciradiate.*



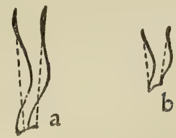
[*a* = ‘*Grammoceras*’ *bassanii* Fucini, ‘Appen. Centr.’ 1900, pl. x, fig. 6; *b* = ‘*Grammoceras celebratum*’ Fucini, *ibid.* pl. x, fig. 2.]

Fig. 3.—*Subanguliradiate.*



[*a* = ‘*Grammoceras*’ *normanianum* var. *costicillatum*, subvar. *detractum* Fucini, ‘Appen. Centr.’ 1900, pl. viii, fig. 3; *b* = ‘*Harpoceras*’ *cornacaldense* Tausch, 1890, pl. i, fig. 2.]

Fig. 4.—*Angulirursiradiate.*



[*a* = ‘*Hildoceras*’ *lavinianum* Mgh., var. *conjungens* Fucini, ‘Mte. Cetona’ 1905, pl. v (xlv), fig. 11; *b* = ‘*H.*’ *l.* var. *retroflexum* Fucini, *ibid.* pl. iii (xliii), fig. 7.]

A brief formal diagnosis of the new genus might, then, be framed as follows:—General form of the shell resembling *Seguenziceras* as here emended: that is, more or less evolute; compressed or quadrate in section, and always keeled—the venter ranging from acute to carinatisulcate. The ornament consists of falciradii, varying within the limits defined in the foregoing table (p. 550). Sutures like *Seguenziceras.*

The introduction of subgenera will have to be delayed until a study of the suture-lines has been accomplished. Further, I believe that no careful observations have been made hitherto, as to the succession in time of the various forms discussed here. Most of them are quoted from the '*margaritatus*' zone; but I think it probable that the two subdivisions of the new genus here established are later than, and have developed from, the older Seguenzicerates of *algovianum* type, with increase and decrease of peripheral projection respectively, added to a flexiradius. Increased knowledge may permit us further to separate from the forms described here two apparently distinct lineages: that of '*Harpoceras (?)*' *dilectum* Fuc.,[1] which tends to develop a typical Harpocerate undercut umbilical edge, but is still subfalciradiate; and that of *Ammonites acutus* Tate, a 'perfalciradiate' form, in which the strong and notched carina becomes so conspicuous a feature.

PROTOGRAMMOCERAS CORNACALDENSE (Tausch) var. ZEUGITANUM nov. (Pl. LII, figs. 1 *a* & 1 *b*.)

Comparable forms:—

1867–81. *Harpoceras pectinatum* Meneghini, 'Fossiles du Medolo' [in Stoppani's 'Paléont. Lombarde' ser. 4, App.] p. 6 & pl. i, figs. 1–3.
1884. *Harpoceras normanianum* (d'Orb.) Wright, 'Lias Ammonites' Monogr. Pal. Soc. p. 470 & pl. lxxxiii, figs. 1–2.
1890. *Harpoceras cornacaldense* Tausch, 'Fauna d. grauen Kalke der Südalpen' Abhandl. K.K. Geol. Reichsanst. vol. xv, pt. 2, p. 36 & pl. i, fig. 1.
1895. *Harpoceras (?) cornacaldense* Tausch, var. *bicicolæ* Bonarelli, 'Fossili Domeriani della Brianza' Rendic. R. Ist. Lombard. ser. 2, vol. xxviii, p. 339.
1900. *Grammoceras normanianum* (d'Orb.) var. *inseparabile* Fucini, 'Amm. del Lias Medio dell' Appennino Centrale' Pal. Ital. vol. vi, p. 29 & pl. viii, fig. 5.
1900. *Hildoceras cornacaldense* Tausch, mut. *medolense* Bettoni, 'Fossili Domeriani della Provincia di Brescia' Mém. Soc. Paléont. Suisse, vol. xxvii, p. 63.
1909. *Harpoceras cornacaldense* (Tausch) Rosenberg, 'Liasische Cephal.-Fauna der Kratzalpe' Beitr. Paläont. Geol. Œsterr.-Ung. vol. xxii, p. 307 & pl. (vii) xvi, figs. 1–2.

The specimen is a cast in compact grey limestone, and has the following dimensions:—

Diameter	60 millimetres.
Height of the last whorl	30 per cent. of the diameter.
Thickness of the last whorl	18 per cent. of the diameter.
Umbilicus	46 per cent. of the diameter.

The whorls are much compressed, and show the peculiar wedge-like thinning towards the periphery characteristic of all the forms

[1] 'Cefalop. Liass. del Mte. di Cetona' pt. 4, Pal. Ital. vol. x (1904) p. 278 (244) & pl. xxxix (xviii), figs. 11–12.

belonging to this group. The ventral area is carinatisulcate on the last whorl; the penultimate one is more rectangular, with a tabulate periphery and a high keel, which is probably hollow, although the crystalline infilling does not let this character show itself very clearly. The inner whorls are much compressed and oval-lanceolate in section, with an acute periphery. The umbilicus is wide (the inclusion being rather less than a quarter) with well-defined perpendicular walls, but a rounded border.

The ornament consists of very close costæ, which seem to degenerate into irregular striæ towards the end; both have a very distinct bend at the inner third of the side (subanguliradiation), and the outer part of the radial curve is somewhat rursiradiate, has only slight peripheral projection, and becomes indistinct before reaching the ventral area. This kind of ornament is limited to the outer whorls only, however; before then the ribs are much stronger and more distant, and, finally, disappear altogether on the inner whorls.

The suture-line is, unfortunately, not clearly visible, but seems to agree with that of the type.

The form here described differs from Dr. Tausch's form in the larger umbilicus (46 per cent. of the diameter instead of 42) and in the beginning of degeneration of the ornament.

The form which Dr. Rosenberg figures comes very near to the type, and his section 2 *b* (pl. xvi) agrees well with that of my specimen. The costation is also too prominent; and, moreover, it is probably exaggerated, so far as the lateral bend is concerned.

The ammonite figured by Wright has little affinity with A. d'Orbigny's *Ammonites normanianus*, as has been pointed out by several authors. Dr. Geyer[1] thinks that it probably belongs to a form of the *boscense* group, and Fucini compares it with his variety *inseparabile* of '*Grammoceras*' *normanianum* (d'Orb.) since their dimensions agree. Dr. Tausch, on the other hand, says that Wright's form is distinguished from *Harpoceras cornacaldense* Tausch only by its section, which is thicker (20 per cent. of the diameter). According to my measurements on the specimen preserved in the British Museum (Natural History), the umbilicus is 42 per cent. of the diameter: that is, the same as in *H. cornacaldense*. The ornament is, however, stronger and very regular; it consists of eighty-five costæ on the last whorl, and only near the end (of a specimen measuring 30 mm. more in diameter than the shell here described) does degeneration set in. A new name, *Protogrammoceras wrighti*, nom. nov. (=*Harpoceras normanianum* Wright *non* d'Orb.[2]), may well be proposed for this ammonite. I may here add that Wright's figure is not quite correct. The radial line should indicate the lateral angularity at the inner third, and the inner whorls, which are smooth at first,

[1] 'Mittelliasische Cephal. Fauna des Hinter-Schafberg' Abhandl. K.K. Geol. Reichsanst. vol. xv, pt. 4 (1893) p. 18.

[2] 'Lias Ammonites' Monogr. Pal. Soc. (1878–86) p. 470 & pl. lxxxiii, figs. 1–2.

show no excentrumbilication. The venter is narrower than shown in the figure, has finer keels, and agrees better with that of the type than the figure would lead one to believe. Wright mentioned that the history of the specimen was not known; but, judging by the matrix, he thought that it might be of Middle Liassic age. The specimen is labelled 'Upper Lias, Somerset,' although the authority for that statement cannot now be ascertained. If the latter age were correct, we have here a striking example of deceptive homœomorphy; but the different style of the ornament in *Hildoceras* and the catagenetic character of the periphery in *Pseudogrammoceras* from carinatisulcate to fastigate do not suggest connexion of Wright's form with the Toarcian Hildoceratidæ. The suture-line is, unfortunately, not visible on the specimen, and I was unable to break it up.

Fucini's var. *inseparabile* of '*Grammoceras*' *normanianum* (d'Orb.), now more correctly named *Protogrammoceras inseparabile* (Fuc.), has a section similar to that of my specimen and not so thick as that of *Pr. wrighti.* The costation, moreover, is coarser in the earlier part of the last whorl than that of the other forms mentioned here; and the radial line may be straighter laterally, showing the form to be somewhat transitional. Fucini's figure is not good enough to enable one to decide this.

Grammoceras cornacaldense (Tausch) var. *bicicolæ* Bonar., is distinguished by a very small umbilicus (32 per cent. of the diameter); and the same percentage is given by Meneghini for his '*Harpoceras*' *pectinatum*, which agrees (especially fig. 3) very well in section and suture with my specimen, but is subfalciradiate.

In Meneghini's variety iii of '*Harpoceras*' *boscense* Reyn. (=*Grammoceras cornacaldense* mut. *medolense* of Bettoni) the umbilicus is only 30 per cent., and the radial curve, owing to the width of the side and a slight peripheral projection, assumes a pseudofalcate character.

Protogrammoceras aff. costicillatum (Fuc.) var. detractum Fuc.

1900. *Grammoceras normanianum* (d'Orb.) var. *costicillatum* Fuc., forma *detracta* Fucini, 'Amm. del Lias Medio dell' Appennino Centrale' Pal. Ital. vol. vi, pl. viii, figs. 2–3 & p. 30.
1900. *Grammoceras portisi* Fucini, *ibid.* pl. ix, figs. 1–3 & p. 33.
1904. *Hildoceras portisi* Fucini 'Cefalop. Liass. del Mte. di Cetona' pt. 4, *ibid.* vol. x, pl. xx (xli) figs. 7–11 & p. 287.
1900. *Grammoceras portisi* var. *zittelianum* Fuc. 'Amm. del Lias Medio, &c.' *ibid.* vol. vi, pl. ix, fig. 4 & p. 35.
1900. *Grammoceras portisi* var. *contrarium* Fuc. *ibid.* pl. ix, fig. 5 & p. 36.

This form is preserved only as an impression in the same bluish-grey limestone as the other specimens. The ventral portion is missing, and it is impossible, therefore, to say anything definite about the periphery, except that the venter certainly seems to have been fairly acute and the section compressed. The dimensions are as follows:—

Diameter	67 millimetres.
Height of the last whorl	33 per cent. of the diameter.
Umbilicus	40 per cent. of the diameter.

These dimensions agree with Fucini's variety (only the umbilicus is 40 instead of 42 per cent.) and also with his '*Grammoceras*' *portisi*. But the latter has a sulcicarinate, fairly broad venter and more rounded sides, whereas in the former the sulci are faint and the sides flatter; and these characters, together with the sharper umbilical border, bring it near the present variety.

The ornament consists of flexiradii which are somewhat less angular than those of the group described previously, but would still be classed as subanguliradiate. Some of the ribs are united on the inner half of the side, and come out more prominently then, as illustrated in Fucini's fig. 3 *a* of pl. viii. The costation of the inner whorls also seems to agree very well with that given by Fucini.

Of the other forms cited above, the var. *zittelianum* has an umbilicus of 38 per cent. only: in other words, it is smaller than that of my specimen by the same amount as that by which the type *portisi* exceeds it. The costation is too coarse and distant, however; whereas, on the other hand, in the var. *contrarium* it is too fine, and here the umbilicus is but 33 per cent. of the diameter.

Protogrammoceras (?), sp. nov.

Of this form only a small fragment preserved in grey limestone is in my collection; and, if the specimen had not been found in company with fossils of undoubted Mesoliassic age, I probably should not have hesitated to identify it with *Harpoceras bicarinatum* (Ziet.) =*cumulatum* Hyatt, considering the distinctive characters of this form. But, as I pointed out in the first part of this paper (p. 542), despite this apparently close resemblance, due in part, undoubtedly, to the peculiar mode of its preservation, I am inclined to question its affinity to Zieten's form, especially as the umbilicus and the suture-line are unknown.

The specimen shows close agreement with an undoubted *H. bicarinatum* (Ziet.) from Milhau (Aveyron) in my collection, and also with the figures given by P. Reynès [1] and E. Dumortier.[2] Wright's form [3] seems to be less closely costate, but agrees well in its thin and flat section: it is named *H. bicarinatum* (Münster); but, as Prof. Haug has pointed out, Münster's *bicarinatus* is an *Arcestes*. Hyatt's new specific name for Zieten's *Ammonites bicarinatus* is, therefore, superfluous.

Zieten's figure has more rounded sides and a smaller umbilicus [4] than that given by Wright; also the radial line is less falcate. But there seems to be a good deal of variation in this group (the

[1] 'Monographie des Ammonites du Lias Supér.' pl. v, figs. 18–30.

[2] 'Depôts Jurass. du Bassin du Rhône: pt. 4—Lias Sup.' pl. xi, figs. 3–7 & p. 55.

[3] 'Lias Ammonites' Monogr. Pal. Soc. (1878–86) p. 462 & pl. lxxxii, figs. 9–10.

[4] C. H. von Zieten, 'Verstein. Württembergs' 1830, pl. xv, fig. 9.

change in the course of the radial line at least is probably due to incorrect drawings), and another specimen in my collection from Altdorf (Franconia) shows not only a thicker section but also a smaller number of costæ, similar to figs. 5 & 6 of Dumortier.

So far as I am aware, no Mesoliassic forms so thin as this have been described. My specimen has been slightly squashed obliquely, and is worn on one side, but from the inner whorl shown in section I measured the width of the conch to have been at most 7 millimetres at a whorl-height of 16 mm., precisely the same as in *H. bicarinatum* (Ziet.). The periphery is tabulate, with a fine median keel, as figured by Reynès on pl. v, fig. 29 (*non* 27); the latter is apparently hollow, and certainly so on the inner whorl, where the section is more rectangular and the keel strong and high.

'*Grammoceras*' *celebratum* Fucini[1] has evolute whorls and a distant costation. '*Gr.*' *falcicostatum* Fuc.[2] is similar, but approximates more closely to the form here described in its thin section. It is possible that the latter may represent an involute development of this falciradiate group.

In '*Grammoceras*' *bassanii* Fuc.[3] there is closer and finer costation towards the end, but the curve is only subfalciradiate. *Gr. cornacaldense* (Tausch) mut. *medolense* Bettoni,[4] also has subanguliradiate costation; whereas, in the form here described, the radial line is a true Harpocerate sickle with strong forward projection near the periphery. Bettoni's variety, however, somewhat resembles the form here described in its wide and flat sides and narrow periphery.

In the absence of suture, or even umbilicus, the identification of this interesting fragment must remain doubtful; but, as I have stated before, the association with Domerian ammonites makes it probable that it represents a new form, apparently more or less homœomorphous with the typical Toarcian *Harpoceras bicarinatum* (Ziet.).

Gen. nov. sp. nov. (?). (Pl. LII, fig. 2.)

1900. *Lioceras (?) grecoi* Fucini, 'Amm. del Lias Medio dell' Appenn. Centr.' Pal. Ital. vol. vi, p. 65 & pl. xi, fig. 4.

This interesting fragment was found together with the ammonites described in the foregoing pages. Like Fucini's forms it has a much compressed section, but the umbilicus is smaller than that of his fig. 4 *a*, although not quite so small as that of fig. 5 *a*: this might be explained, according to Fucini, by the intermediate size of my fragment.

The greatest thickness also occurs at the inner third of the whorl,

[1] 'Ammoniti del Lias Medio dell' Appennino Centrale' Pal. Ital. vol. vi (1900) p. 41 & pl. x, figs. 1–2.

[2] 'Cefalop. Liass. del Monte di Cetona' *ibid.* vol. x (1904) pl. (xviii) xxxix, fig. 13.

[3] 'Amm. del Lias Medio, &c.' Pal. Ital. vol. vi (1900) p. 46 & pl. x, figs. 6–7.

[4] See p. 554.

from which point the sides slope very gradually to the periphery as well as to the umbilicus, although the final edge at the latter is quite sharp.

The periphery, as in Fucini's forms, is 'little spacious' and narrowly rounded, bearing a small keel. Fucini does not state whether this is solid or hollow, and his illustrations are certainly far from good; but he compares his fossils with ammonites described by Meneghini as *A. lythensis* Y. & B., a form which belongs to the hollow-carinate genus *Pseudolioceras*. The latter author [1] also omits to describe the character of the carina.

Now, on the penultimate whorl the form at present considered is distinctly solid-keeled, like the typical Aalenian Liocerates. The section is here also less lanceolate and quite rectangular, with a comparatively broad periphery.

The ornament consists of strong primary costæ near the umbilicus; and, whereas Fucini's form shows fourteen, my specimen possessed probably eighteen to twenty. These costæ bifurcate at the middle of the side, but somewhat irregularly, and the whole of the radial line describes the double curve which is characteristic of the true Liocerates. There are also intermediate costæ, and altogether the character of the costation agrees exceedingly well with that of *Lioceras gracile* S. Buckm. and, less so, with *L. subcostosum* S. Buckm.,[2] both these true Liocerates coming from the *scissi* beds.

Some Pseudoliocerates show superficial resemblance to this specimen. Quenstedt's *Ammonites* cf. *lythensis* (*non* Y. & B.) pl. liv, fig. 54 ('Amm. d. Schwäb. Jura' 1885), is too thick near the umbilical edge and too involute; whereas the style of costation is comparable with that of the form now described only near the end of the last whorl.

Ammonites elegans (*non* Sow.), figured by P. Reynès,[3] also has a different section, and the costæ do not seem to be biarcuate; *Pseudolioceras beyrichi* Schlœnb.,[4] on the other hand, has an approximately similar radial line.

A new generic name might be introduced for these 'Prolioccerates' of Domerian age; but, as the sutures of neither Fucini's *grecoi* nor of my specimen are known, and as they are altogether poorly preserved, I will neither venture to propose one myself, nor to speculate on the connexion of the group with the other Middle Liassic Hildoceratidæ.

[1] G. Meneghini, 'Fossiles du Medolo' [in Stoppani's 'Pal. Lombarde' ser. 4, App.] p. 13 (*pars*).

[2] 'Inf. Ool. Ammonites: Suppl.' pt. 10, Monogr. Pal. Soc. vol. lii (1898) pl. vi, figs. 11–13 & 5–7.

[3] 'Monographie des Ammonites du Lias Supér.' pl. v: for example, fig. 10.

[4] U. Schlœnbach 'Beitr. z. Paläont. d. Jura- & Kreide-Format. in N.W. Deutschland: I—Jurass. Amm.' Palæontographica, vol. xiii (1865) pp. 170–71 & pl. xxvii; also S. S. Buckman, 'Inf. Ool. Amm.' pt. 3, Monogr. Pal. Soc. vol. xlii (1888) p. 87 & pl. xx, figs. 7–10.

(2) CALLOVIAN.

Genus Reineckeia Bayle.

Reineckeia aff. hungarica Till. (Pl. LII, fig. 3.)

1911. A. Till, 'Amm. Fauna des Kelloway von Villány' Beitr. Paläont. Geol. Œsterr.-Ung. vol. xxiv, p. 10 & pl. i (v), figs. 1–2; also text-fig. 11.

There is one specimen preserved in red marble, streaked with green, and slightly slickensided in places on the back. Its dimensions are:—

Diameter	65 millimetres.
Height of the last whorl	33 per cent. of the diameter.
Thickness of the last whorl	28 per cent. of the diameter.
Umbilicus	40 per cent. of the diameter.

These measurements agree almost exactly with the dimensions given by Dr. Till, and the sculpture and section also are practically identical.

The last whorl shows about thirty-two primary costæ, each giving rise to two or three secondaries of equal strength and strongly prorsoradiate character. The primaries are short sharp ridges rising to an elongated spine at the point of furcation, and only the innermost whorls bear the rounded tubercles which characterize the *anceps* group. There are four constrictions on the last whorl, more strongly inclined forward than the costæ; and since the costæ also bi- and trifurcate somewhat irregularly, and since some of them, especially those bordering the constrictions, remain single throughout, the sculpture is altogether irregular.

The ventral furrow is very distinct, and bordered by the strong slightly-thickened ends of the secondaries, terminating abruptly at the groove.

The umbilicus is wide, with a nearly perpendicular border.

Dr. Till points out the differences of his form from *Reineckeia kiliani* (Par. & Bon.), *R. straussi* (Weith.), *R. greppini* (Opp.), and *R. fraasi* (Opp.). The ammonite under consideration also bears but little resemblance to these forms.

From *R. greppini* (Opp.) in Till (pl. vi, figs. 4–7) the form here described is distinguished by its smaller umbilicus. Dr. Till does not give the measurements; but, according to his figure, the umbilicus equals about 44 per cent. of the diameter, not 40 as in my specimen: the section also is too thin near the periphery. On the other hand, there is very close agreement in the ornament. The characteristic concave shape of the primary costæ, leading up to the radially elongated spine at the point of bi- or trifurcation, is very distinctive, just as in my specimen; whereas *R. hungarica* Till, the commonest form at Villány, has primaries which are raised into a sharp crest at the middle, not at the end of the

short rib. This is the only notable point in which my specimen differs from *Reineckeia hungarica* Till, and approaches *R.* cf. *greppini* (Opp.) Till. I am inclined to consider it an intermediate form, with the *greppini* stage persisting a little longer, and the branching of the secondaries immediately off the umbilical border only occurring once or twice near the end.

R. transiens Till is a transitional form to still more perisphinctoid ammonites, and also resembles my specimen somewhat closely. It has fewer primaries, however (twenty-eight), and its umbilicus (37 per cent. of the diameter) is considerably smaller.

The two ammonites which Waagen figures on pl. lvii, fig. 4 & pl. lix, fig. 1 ('Cephal. of Kutch') as *R. anceps* (Rein.), although they really belong to the *greppini* group, show a similar style of ornament, but are more widely umbilicated (44 and 47 per cent.). The first figure (= *R. waageni* Till) has less numerous and less sharp costæ, and they divide more in the middle of the side, not at the inner fourth. In *R. eusculpta* Till this point of bifurcation has moved still more towards the middle of the side, whereas the section is here quadrate. Waagen's second form (= *R. reissi* Steinmann) has the tubercles more strongly developed.

The *Reineckeia* to which I referred in the first part of this paper (p. 543), from Foum Islamen, Constantine, differs from all the forms mentioned here in its rounded whorls and strong costation. It shows a highly coronate stage persisting almost to the end, and belongs therefore to the true *anceps* group = *substeinmanni* group of Dr. P. Lemoine.

The suture-line is not shown on my specimen, but there can be no doubt about the Callovian age of the ammonite.

I may add that, as the Upper Jurassic was known to occur on Jebel Zaghuan, I first endeavoured to compare my specimen with those Kimmeridgian and Tithonian forms which were at one time included in the genus *Reineckeia*. But the resemblance is, in reality, only quite superficial. For example, *Aulacostephanus phorcus* Font.[1] has similar dimensions, but distant tubercles, not close primary costæ, around the umbilicus; and in the genus *Acanthodiscus* (as, for example, *A. andreæi* Kil.[2] and *A. chaperi* Pictet [3]) the tuberculate character of the ornament is still more distinct, whereas the resemblance with certain forms of *Himalayites* Uhlig [4] is also merely superficial. Apart from the costation, the character of the constrictions and chiefly the inner whorls clearly distinguish the Callovian *Reineckeiæ* from these Upper Jurassic forms.

[1] See E. Dumortier & F. Fontannes, 'Descr. des Amm. de la Zone à *Amm. tenuilobatus* de Crussol' 1876, p. 108 & pl. xv, fig. 3; also P. de Loriol, 'Monogr. Pal. des Couches de la Zone à *Amm. tenuilobatus* de Baden (Argovie)' Mém. Soc. Pal. Suisse, vol. v (1875) pl. xvi, fig. 4.

[2] W. Kilian, 'Mission d'Andalousie: II—Études Paléont. sur les Terrains Secondaires & Tertiaires de l'Andalousie' Mém. Ac. Sci. Paris, vol. xxx (1889) p. 670 & pl. xxxii, fig. 1.

[3] F. J. Pictet, 'Mél. Pal.' pt. 4, 1868, p. 242 & pl. xxxvii, figs. 1–3.

[4] V. Uhlig, 'Fauna of the Spiti Shales' Pal. Indica, ser. 15, vol. iv (1910) pl. xxxviii.

Genus PERISPHINCTES Waag. *em.* Siem.

PERISPHINCTES cf. BIENIASZI Teiss. (Pl. LII, fig. 4.)

1899. J. von Siemiradzki, 'Monogr. Beschreib. d. Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv, p. 302 & pl. xxvi, fig. 49.

This is the only specimen of *Perisphinctes* found in the *anceps* zone of the Poste Optique; and, although it resembles, in its red marble matrix, the many perisphinctoid forms collected in higher beds on another side of the mountain, it is clearly distinguished by its ventrally rursicostate ornament. The specimen consists of only a poorly-preserved cast, and its dimensions are:—

Diameter	110 millimetres.
Height of the last whorl	31 per cent. of the diameter.
Thickness of the last whorl	27 per cent. of the diameter.
Umbilicus	46 per cent. of the diameter.

The specimen is septate throughout, and its diameter would, therefore, be considerably increased by the presence of the body-chamber, which is of importance in view of the affinities of the ammonite to *Grossouvria.*

The whorls are compressed: that is, the section is higher than wide, especially towards the end, showing flat sides between a rounded, but distinct, umbilical border and a circular periphery. The whorl is thickest near the umbilical border.

The umbilical wall itself is almost perpendicular, and the umbilicus moderately deep and wide. The inclusion is rather less than half of the previous whorl.

The last whorl of the specimen here described is very badly preserved; but, at about 70 mm. diameter, the ornament consists of some thirty-five primary costæ which are thickened, slightly prorsoradiate, and virguloid, with the concave side forwards. They begin on the umbilical edge, and reach to the middle of the side, where they bi- or trifurcate, so that on the periphery we can count about 110 delicate rursiradiate costæ. Some intercalated secondaries also occur. The course of the whole of the radial curve is therefore sigmoidal, and this character is shown also by the two constrictions on the whorl (at 70 mm. diameter), although these latter are more oblique: that is, more distinctly prorsoradiate. Slight attenuation of the secondaries is shown along the median line of the periphery. Parabolar knobs are not visible.

The inner whorls, unfortunately, are very badly preserved, but seem to be regularly costate, as in Quenstedt's *Ammonites convolutus gigas.*[1]

The suture-line is similar to that given by Quenstedt[2] for an ammonite which Siemiradzki includes in the synonymy of *Perisphinctes orion* (Opp.), and resembles also that of *Grossouvria curvicosta* (Opp.) as given by Siemiradzki.[3]

[1] 'Amm. d. Schwäb. Jura' 1887, pl. lxxxi, fig. 21 & p. 693.

[2] 'Cephalopoden' 1849, p. 171 & pl. xiii, fig. 6.

[3] 'Monogr. Beschreib. d. Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv (1898) p. 97 & fig. 8.

If then, despite this close agreement in dimensions and all details, I do not entirely identify my specimen with the type, it is on account of its bad state of preservation.

The ammonite which M. Neumayr figures and describes[1] as *Perisphinctes curvicosta* (Opp.), but belongs, according to Siemiradzki, to the group of *P. caroli* Gemm., shows much resemblance to the form here described. Its section is, however, wider; the costæ are more strongly sigmoidal and rursiradiate; there are parabolar knobs; and altogether the ammonite has still much more affinity with the typical *Grossouvriæ* than with the form here described, and has probably been excluded from that subgenus only on account of its large size. It may be considered a transitional form from the *Grossouvria-curvicosta* group to the groups of *Perisphinctes caroli* and *P. orion*, the latter including the ammonite here described with initial Perisphinctate costation of a more prorsorectiradiate character and much larger dimensions.

With the true *Perisphinctes curvicosta* (Opp.) Siem.,[2] and especially *P. curvicosta* (Opp.) in Waagen,[3] which has a very irregular ornament and rounded section, there is, therefore, correspondingly less agreement.

Dr. Till figures a *Perisphinctes* cf. *curvicosta* (Opp.),[4] which also bears a certain resemblance to the form here described; but in this the costation is similarly rursiradiate and the umbilicus is too narrow. Of the other forms figured by the same author, only *P. villányensis* Till and *P. leptoides* Till somewhat resemble my specimen. In the former the umbilicus is narrower, and the primary costæ are fewer than in my specimen. *P. leptoides* has parabolar knobs and a section too wide near the periphery.

With the other ammonites included in the groups of *P. caroli* and *P. orion*, my specimen is less closely comparable.

(3) UPPER JURASSIC.

Genus Phylloceras Suess.

Phylloceras cf. mediterraneum Neum.

1898. A. de Riaz, 'Description des Ammonites des Couches à *Peltoceras transversarium* de Trept (Isère)' pl. xvi, figs. 9–10 & p. 40.

Seven out of fourteen Phyllocerates belong to this form, which seems fairly common at Sidi Bu Gubrîn. These agree very closely with the figures given by A. de Riaz; and the form is, indeed, easily recognized by its comparatively-wide umbilicus, its five

[1] 'Cephalop. Fauna d. Oolithe von Balin' Abhandl. K.K. Geol. Reichsanst. vol. v (1871) pl. xii, fig. 2 & p. 34.

[2] 'Monogr. Beschreib. d. Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv (1898) p. 96.

[3] 'Jurassic Fauna of Kutch' Pal. Indica, ser. 9, vol. i (1873) pl. xxxix, figs. 4–6 & p. 169.

[4] 'Amm. Fauna des Kelloway von Villány' Beitr. Paläont. Geol. Œsterr.-Ung. vol. xxiv (1911) pl. (iv) viii, fig. 5.

gently-bent constrictions, slightly rursiradiate near the periphery, and its trifid lateral lobe.

With the material at my disposal: that is, imperfect casts bearing no trace of the shell-ornament, and showing only the suture-line in disconnected portions, it is impossible to decide whether the form should really be included in Neumayr's *Ph. mediterraneum*; but the smaller number of constrictions (which seems very constant) may well enable us to separate the Argovian forms from the type.

Neumayr's form [1] came from the *macrocephalus* zone, and closely comparable ammonites from the same beds have been figured by Gemmellaro,[2] Popovici-Hatzeg,[3] and others. Dr. P. Lemoine [4] has recently created the var. *indica* for the Indian form of *Ph. mediterraneum* Neum. figured by Waagen,[5] which occurs also in Madagascar, being distinguished by less inclusion and a wider umbilicus. All these Callovian forms have seven (or eight) constrictions.

Dr. M. Canavari[6] describes the form from the *Aspidoceras-acanthicum* beds. As he figures only a fragment, it is impossible to say whether there is agreement with the Callovian forms; but the Argovian forms, at any rate, seem already distinct, and we may reasonably doubt whether the ammonite really persisted from the *macrocephalus* zone to the uppermost Jurassic, as is generally assumed.

Phylloceras zignodianum (d'Orb.), a form which differs only in having more angular constrictions and a bifid lateral saddle, does not seem to occur in Mediterranean deposits.

An eighth specimen in my collection from Zaghuan has straighter constrictions and a smaller umbilicus than the other seven; but as the specimen is worn, and as one of A. de Riaz's figures [7] also shows constrictions which on the cast are almost straight, I include it here.

PHYLLOCERAS cf. SUBPTYCHOICUM Dacqué. (Pl. LIII, fig. 1.)

1873. W. Waagen, 'Jurassic Fauna of Kutch' Pal. Indica, ser. 9, vol. i, p. 30 (*pars*) [as *Ph. ptychoicum*] & pl. vii, fig. 2.
1910. E. Dacqué, 'Dogger & Malm aus Ostafrika' Beitr. Paläont. Geol. Œsterr.-Ung. vol. xxiii, p. 7 & pl. ii, fig. 1.

One specimen in the collection belongs to the *ptychoicum* group, but no labial ridges are visible. These, most probably, have been worn down; but, since they are absent on the chambered parts

[1] 'Jurastud. 3: Phylloceraten des Dogger & Malm,' Jahrb. K.K. Geol. Reichsanst. vol. xxi (1871) p. 340 & pl. xvii, figs. 2–5.

[2] 'Faune Giur. & Liass. della Sicilia' 1872–82, pl. xvii, fig. 2.

[3] 'Céphal. Jurass. moyen du Mt. Strunga' Mém. Soc. Géol. France (Paléont.) vol. xiii (1905) No. 35, pl. iii, figs. 9 & 10.

[4] 'Pal. Madagascar: pt. 8—Amm. d'Analalava' Ann. Paléont. vol. v (1910) p. 3 & pl. i, fig. 1.

[5] Pal. Indica, ser. 9, vol. i (1873) p. 34 & pl. v, fig. 1, pl. vii, fig. 3.

[6] 'Fauna degli Strati con *Aspidoceras acanthicum* del Mte. Serra' Pal. Ital. vol. ii (1896) p. 38.

[7] 'Description des Ammonites des Couches à *Peltoceras transversarium* de Trept (Isère)' 1898, pl. xvi, fig. 10.

of the younger shells belonging to this group, and since my cast is septate throughout, it is possible that they never existed on the specimen. The dimensions are:—

Diameter	80 millimetres.
Height of the last whorl...........	57 per cent. of the diameter.
Thickness of the last whorl	42 per cent. of the diameter.
Umbilicus............................	8 per cent. of the diameter.

These measurements agree closely enough with Waagen's figures, and the flattened sides and gentle slope towards the umbilicus, shown on my ammonite, are also characteristic of the Indian form. On the other hand, the suture-line of the specimen, though worn at the periphery, shows only a subtetraphylloid external saddle, and the first lateral saddle is subdiphylloid; altogether quite like those of *Phylloceras euphyllum* Neum.

No similar intermediate form between the latter, which ranges, according to Neumayr, from the *macrocephalus* to the *cordatus* beds, and the typical Tithonian *Phylloceras ptychoicum* Quenst. (see especially K. A. von Zittel's 'Stramberger Schichten' pl. iv for figures) seems to have been described from European deposits. *Phylloceras subptychoicum* Dacqué occurs in India and German East Africa in the '*perarmatum*' zone, and differs, as we have seen, in its clearly tetraphylloid lateral saddle. According to its author, the Corallian form differs from the younger *Ph. ptychoicum* Quenst. in having on the umbilical side of the external saddle a peculiar leaflet below the summit-branches; and an identical arrangement is observable on my specimen.

Phylloceras feddeni Waagen,[1] from the same zone of India and Madagascar, has the external saddle still diphylloid and only the peripheral leaflet shows initial division. The umbilicus in this form is deeper, moreover, and the section wider, coming nearer to the true *Ph. ptychoicum* (Quenst.). Waagen erroneously gave the thickness as only 22 per cent. of the diameter, but his illustration shows that this figure must at least be doubled.

Ph. jaraense Waagen[2] has a different section and a rosette of short curved constrictions at the umbilicus. Its suture-line is not unlike that of my specimen; the external saddle is tetraphylloid, but the siphonal lobe is almost as long as the lateral lobe, and the first lateral saddle is also tetraphylloid.

Ph. insulare Waagen[3] also has a different section and a very long siphonal lobe.

With regard to all these forms of Indo-Malagasy affinities, it is interesting to note that Pervinquière[4] considers the *Perisphinctes beyrichi*, described by Futterer[5] from the Jurassic of German East Africa, to be identical with his *P. adelus* Gemm. found in Tunis and Sicily.

[1] 'Jurassic Fauna of Kutch' 1873, pl. vii, fig. 1 & p. 27.
[2] *Ibid.* pl. v, fig. 6 & p. 28. [3] *Ibid.* pl. ix, fig. 3 & p. 29.
[4] 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' 1907, p. 23.
[5] 'Beitr. z. Kenntn. d. Jura in Ost-Afrika' Zeitschr. Deutsch. Geol. Gesellsch. vol. xlvi (1894) p. 9 & pl. ii, figs. 1–3.

PHYLLOCERAS MANFREDI (Oppel).

1863. *Ammonites manfredi* Oppel, 'Ueber Jur. Amm.' Pal. Mitt. Mus. d. K. Bayerisch. Staates, p. 215 & pl. lvii, fig. 2.
1871. *Phylloceras manfredi* Neumayr, 'Jurastudien: 3—Phylloceraten des Dogger & Malm' Jahrb. K.K. Geol. Reichsanst. vol. xxi, p. 37 & pl. xiv, fig. 8.
1907. *Phylloceras* cf. *manfredi* Pervinquière, 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' p. 13.

A small ammonite, not very well preserved, seems to agree with this form; its dimensions are:—

Diameter	23 millimetres.
Height of the last whorl	55 per cent. of the diameter.
Thickness of the last whorl	38 per cent. of the diameter.
Umbilicus	9 per cent. of the diameter.

These dimensions agree with those given by Neumayr. There are also four constrictions which begin indistinctly near the umbilicus, and become wider and more conspicuous near the periphery. The sides are bulging (as figured by Neumayr), and what can be seen of the suture agrees also with fig. 8 *b* of that author.

Pervinquière records this form from Jebel Zaghuan, but thinks that it is very difficult to determine whether his three small ammonites belong really to the form here described or to *Ph. puschi* (Oppel). My specimen shows neither the numerous constrictions, nor the thin section and small umbilicus, of the latter form.

The state of preservation of a second specimen, which I refer doubtfully to *Ph. manfredi* (Oppel), is rather bad.

PHYLLOCERAS cf. SAXONICUM Neum.

1871. M. Neumayr, 'Phylloceraten des Dogger & Malm' Jahrb. K.K. Geol. Reichsanst. vol. xxi, p. 315 & pl. xiii, fig. 4, pl. xiv, figs. 1–2.
1907. L. Pervinquière, 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' p. 12.

A poorly-preserved cast, referred doubtfully to this form, has the following dimensions:—

Diameter	90 millimetres.
Height of the last whorl	60 per cent. of the diameter.
Thickness of the last whorl	32 per cent. of the diameter.
Umbilicus	3 per cent. of the diameter.

Neumayr's form agrees so far very well, and in section especially; but on my specimen no trace of the umbilical rosette of virguloid grooves is to be seen. Pervinquière also mentions a rather badly-worn specimen from the Lower Tithonian of Jebel Ben Saidan, and this approaches to *Ph. saxonicum* Neum. in thickness, but has no rosette. What there is to be seen of the suture-line, especially the diphylloid external saddle and the triphylloid first lateral saddle, seems to agree equally well with Neumayr's type.

Since my specimen shows no trace of the original shell-ornament, no comparison can be made with *Ph. dyscritum* Canavari—a form distinguished from *Ph. saxonicum* Neumayr by prorsiradriate lineation, instead of recti- to rursicostation.

PHYLLOCERAS cf. ISOTYPUM (Benecke).

1865. E. W. Benecke, 'Ueber Trias & Jura in den Südalpen' Geogn. Pal. Beitr. p. 184 & pl. vii, figs. 1–2.
1871. M. Neumayr, 'Phylloceraten des Dogger & Malm' p. 314 & pl. xiii, fig. 3.
1896. M. Canavari, 'Strati con *Aspidoceras acanthicum* del Mte. Serra' p. 32.
1907. L. Pervinquière. 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' p. 11.

One small ammonite in the collection seems to be comparable with Benecke's form. It has the flattened sides, deep umbilicus bordered by steep walls, and radial striation at the periphery: the section, however, is not rounded-quadrate, but more elliptical. Its thinness excludes it also from the var. *appenninicum* Canav. of *Ph. isotypum* (Ben.).

A larger specimen has the somewhat broadened venter of Benecke's form, but the umbilicus is smaller and fairly shallow, although it may only have been worn down. It resembles in this respect *Phylloceras serum* (Oppel); but the latter ammonite is much thinner, especially near the periphery.

This ammonite is very common in the '*acanthicus*' zone of the Alps and Sicily, and Pervinquière has recorded it (although not with certainty) from Jebel Ben Saidan in Tunisia. I have not come across any Argovian *Phylloceras* with which my specimens could be compared; but, in view of the fact that they were collected together with a large number of *transversarius*-zone fossils, I may mention that there is a possibility of the first specimen representing the inner whorls of *Ph. plicatum* Neumayr. It has the peripheral ornament, but differs apparently in the umbilicus. In any case, it must be remembered that it is a young specimen, and that the other ammonite, as well as *Phylloceras* cf. *saxonicum* Neum., described previously, are worn specimens, so that their attribution to the '*acanthicus*' zone is doubtful.

According to Dr. Pompeckj,[1] *Ammonites heterophyllus albus* Quenstedt,[2] from the *bimammatum* zone of Laufen, differs from Benecke's type only in having a narrower umbilicus and less flat sides.

Genus SOWERBYCERAS Par. & Bon.

SOWERBYCERAS PROTORTISULCATUM (Pomp.). (Pl. LIII, figs. 2*a*–2*c*.)

1893. J. F. Pompeckj, 'Beiträge zur Revision der Ammoniten d. Schwäbischen Jura' pt. 1, p. 53 & pl. ii, figs. 1–2.
1907. L. Pervinquière, 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' p. 15.

This easily-recognizable ammonite is exceedingly common at Sidi Bu Gubrîn, and I can identify twenty-one specimens with Pompeckj's types, whereas only two specimens appear to belong to a different form of *Sowerbyceras*. They are all casts, and the measurements of eleven forms are as follows:—

[1] 'Beitr. z. Revision d. Ammon. d. Schwäbischen Jura' pt. 1, 1893, p. 28.
[2] 'Ammoniten d. Schwäbischen Jura' 1888, p. 901 & pl. xcvii, fig. 7.

Diameter.	*Height.*	*Thickness.*	*Umbilicus.*
Millimetres.	Per cent.	Per cent.	Per cent.
20	45	45	25
21	43	43	25
21	42	43	26
22	42	41	27
23	44	45	22
25	45	48	24
36	42	47	25
37	46	48	22
41	44	41	22
42	43	40	26
43	44	42	24

The other specimens are less well preserved. I state the dimensions in detail, because they show that, despite some variation, the height of the last whorl is almost equal to the thickness; whereas in *Sowerbyceras tortisulcatum* (d'Orb.), which, moreover, belongs to the *athleta* zone, the proportion of height to thickness is about 4 : 3. This, together with the sharp and high umbilical edge, was the principal distinction in separating the Argovian forms from A. d'Orbigny's 'Oxfordian' type.

Pervinquière records from Jebel Zaghuan one fragment and three small ammonites, referable to *Sowerbyceras tortisulcatum* (d'Orb.), and associated with *Ochetoceras arolicum* (Opp.) and other Argovian ammonites. They also doubtless belong to the same form as the specimens here described.

SOWERBYCERAS cf. LORYI (Munier-Chalmas).

1876. *Ammonites (Phylloceras) silenus* Dumortier & Fontannes, 'Descr. des Amm. de la Zone à *Amm. tenuilobatus* de Crussol' p. 33 & pl. v, fig. 2.
1877. *Phylloceras silenus* in Gemmellaro, 'Faune Giur. & Liass. della Sicilia' p. 185 & pl. xvi, figs. 1–3.
1907. *Phylloceras loryi* in Pervinquière, 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' p. 15 & pl. i, figs. 1–2.

The two specimens which I refer to this form have the following dimensions:—

	No. 1.	*No.* 2.
Diameter	37 mm.	33 mm.
Height of the last whorl	50	49 per cent. of the diameter.
Thickness of the last whorl	? 40	43 per cent. of the diameter.
Umbilicus	17	18 per cent. of the diameter.

The narrower umbilicus, with sloping walls and rounded edge, combined with the absence of constrictions, seems to separate these two ammonites from *Sowerbyceras protortisulcatum* (Pomp.). Since the specimens are not very well preserved, however, the identification must remain doubtful; and, in view of the fact that I collected a great number of Sowerbycerata and other forms of the *transversarius* zone at the same place, I hesitate to assume a later age for these two imperfect specimens.

Pervinquière mentions one specimen of *Sowerbyceras loryi* (Mun.-Ch.) from Zaghuan; but, near the neighbouring Jebel Ben Saidan, he collected some twenty specimens of *S. loryi* in the

acanthicus zone, and he therefore regards the present form as the commonest Tithonian ammonite of Tunis. Its rarity or absence at Sidi Bu Gubrîn is consequently very significant.

Genus Lytoceras Suess.

Lytoceras cf. gastaldii Gemmellaro.

1870. *Lytoceras montanum (pars)* Gemmellaro, 'Fauna del Calcario à *Terebratula janitor* del Nord di Sicilia' Giorn. Sci. Nat. Palermo, pt. 1, p. 33 & pl. vi, fig. 1.
1872. *Lytoceras orsinii* Gemmellaro, 'Faune Giur. & Liass. della Sicilia' p. 33 & pl. viii, figs. 2–3.
1875. *Lytoceras gastaldii* Gemmellaro, *ibid.* p. 114.
1898. *Lytoceras* cf. *polyanchomemum* (Gemm.) De Riaz, 'Description des Ammonites des Couches à *Peltoceras transversarium* de Trept (Isère)' p. 39 & pl. xvi, fig. 4.

The dimensions of the specimen which I refer here are :—

Diameter	37 millimetres.
Height of the last whorl	38 per cent. of the diameter.
Thickness of the last whorl	35 per cent. of the diameter.
Umbilicus	43 per cent. of the diameter.

The wide umbilicus and hardly overlapping, slowly increasing whorls, with section slightly higher than wide, agree well with the type. The cast is smooth, however, and no trace of the original shell-ornament is left.

Another specimen has a smaller umbilicus (40 per cent. of the diameter only) and possibly more flattened sides, similar to *Lytoceras subtile* (Opp.); but, as the specimen is somewhat worn, specific determination becomes very difficult. Oppel's type comes from the Tithonian of Stramberg; on the other hand, *L. polyanchomemum* Gemm., with which A. de Riaz compares a specimen from the *transversarius* zone of Trept, has been described from the *macrocephalus* beds of Sicily. According to Gemmellaro, the Sicilian form has an umbilicus measuring only 38 per cent. of the diameter, and a high elliptical section; De Riaz's form is more evolute, however, and comes nearer the form to be described next.

In *Lycoceras orsinii* Gemm. the umbilicus is 40 to 43 per cent., as in my two ammonites; but the better-preserved specimen, at any rate, seems to resemble the Argovian form more than it resembles this *acanthicus*-zone fossil. It is unfortunate that one cannot express an emphatic opinion on the age of these forms; but, as I have pointed out before, the fact is very significant that among a large number of forms belonging to the *transversarius* zone, the apparent exceptions should belong to the little-changing genera *Lytoceras* and *Phylloceras*.

Lytoceras aff. polycyclum Neum.

1873. M. Neumayr, 'Fauna der Schichten mit *Aspidoceras acanthicum*' Abhandl. K.K. Geol. Reichsanst. vol. v, p. 160 & pl. xxxi, fig. 4.
1877. G. G. Gemmellaro, 'Faune Giur. & Liass. della Sicilia' p. 188 & pl. xvi, fig. 5.
1907. L. Pervinquière, 'Études de Paléontologie Tunisienne; I—Céphalopodes des Terrains Secondaires' p. 17 & pl. i, fig. 4.

This ammonite is very evolute, the umbilicus measuring, at least,

48 per cent. of the diameter. It greatly resembles Neumayr's form from the *acanthicus* zone, and also *Protetragonites quadrisulcatus* (d'Orb.) from the Tithonian. It is perfectly smooth, however, and shows neither the sulci of the latter form nor the periodic ridges indicated in Gemmellaro's figure of *Lytoceras polycyclum*.

The whorls, although circular and hardly touching on the inner part of the shell, seem to be greatly depressed at the end. It is probable that this character is merely due to squashing of the last whorl, which is incomplete. If not squashed, the specimen would have greatly exceeded, in this depression of the outer whorl, *L. liebigi* (Opp.), which has been quoted from Jebel Zaghuan together with Argovian ammonites; but, as it is a typical Tithonian form, I am inclined to think the identification at fault.

The specimen which A. de Riaz figures as *L.* cf. *polyanchomemum* Gemm. is more involute than my form; in all probability, its section also is different. I have not come across the description of any other widely-umbilicated *Lytoceras* from the *transversarius* zone.

Genus Ochetoceras Haug.

Ochetoceras arolicum (Oppel).

1863. A. Oppel, 'Ueber Jur. Amm.' Pal. Mitt. Mus. d. K. Bayerisch. Staates, p. 188 & pl. li, figs. 1–2.
1907. L. Pervinquière, 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' p. 18.

The two specimens in my collection consist of only septate whorl-fragments, but the characters of this thin and smooth tricarinate form are very distinct, and the identification therefore reliable.

The form is a characteristic fossil of the Argovian (Pervinquière says of the 'Lower Oxfordian'), and has been recorded already from the Poste Optique on another side of the mountain of Zaghuan.

Ochetoceras canaliculatum (Münster).

1830. Münster, in C. H. von Zieten, 'Verstein. Württ.' p. 37 & pl. xxviii, fig. 6.
1831. L. von Buch, 'Recueil de Planches de Pétrif. Remarq.' pl. i, figs 6–8.
1863. A. Oppel, 'Ueber Jur. Amm.' Pal. Mitt. Mus. d. K. Bayerisch. Staates, p. 157 & pl. li, fig. 3.
1898. A. de Riaz, 'Description des Ammonites des Couches à *Peltoceras transversarium* de Trept (Isère)' p. 49 & pl. xvii, figs. 4–6.

My specimen agrees with the figures cited above, as also with specimens that come from the *transversarius* zone of Aargau and from Les Vraconnaz (Vaud). The form is a characteristic Argovian ammonite, and occurs almost throughout the whole range of the *transversarius* zone from South-Western Poland through the Carpathians, the Alps, France, and Spain to North Africa.

Ochetoceras sp.

1875. *Ammonites hispidus* (Opp.) Favre, 'Description des Fossiles du Terrain Jurassique de la Montagne des Voirons' Mém. Soc. Pal. Suisse, vol. ii, p. 27 & pl. ii, fig. 8.

This genus is further represented by the inner whorls of a form

probably like *O. hispidum* Opp. as figured by Favre, or even like *O. canaliculatum* Von Buch. It is only towards the end of the last whorl that the crescents of the outer area appear; previously to that the sides are smooth, and show only the spiral groove.

Genus TARAMELLICERAS de Camp.

TARAMELLICERAS cf. ANAR (Oppel).

1863. A. Oppel, 'Ueber Jur. Amm.' Pal. Mitt. Mus. d. K. Bayerisch. Staates, p. 207 & pl. lv, fig. 1.
1871. M. Neumayr, 'Jurastudien: 4—Die Vertretung der Oxfordgruppe im östlichen Theile der Mediterranen Provinz' Jahrb. K.K. Geol. Reichsanst. vol. xxi, p. 366 & pl. xviii, fig. 5.

The first half of the last whorl of my specimen is quite smooth (perhaps worn), and it is only with some hesitation that I refer it to Oppel's form. The latter part of the last whorl, however, is much like fig. 1 *d* of Oppel's pl. lv, and the specimen also agrees in section and umbilicus so well with the figures, that, if not identical with the type, it must at least represent a very closely-allied form.

Neumayr's specimen differs from mine in section, as well as in its larger umbilicus, and it seems doubtful whether it is really identical with Oppel's type.

Genus LISSOCERAS (?) Bayle.

'LISSOCERAS' ERATO (d'Orb.).

1847. A. d'Orbigny, 'Pal. Franç.: Terr. Jurass.—Céphal.' p. 531 & pl. cci, figs. 3–4.
1875. E. Favre, 'Descr. des Foss. du Terrain Jurass. de la Montagne des Voirons' Mém. Soc. Pal. Suisse, vol. ii, p. 28 & pl. i, fig. 15 *a*.

A small ammonite, somewhat fragmentary, but showing the inner whorls well, clearly belongs to this form. Its smoothness and flatness, combined with a rounded venter and fairly open umbilicus, make it easily recognizable.

Another nearly complete and larger specimen has the umbilicus somewhat narrower, probably measuring only 27 per cent. of the diameter, as compared with the 30 per cent. in D'Orbigny's type. It also seems that the periphery is slightly more acute in my specimen than in the type; but, as the ammonite is worn, I include it with the other specimen in D'Orbigny's well-known 'species,' which is so common a fossil of the Argovian.

In accordance with present custom, I leave his form in the genus '*Lissoceras*' Bayle (= *Haploceras* Zittel); but there can be no doubt that the Argovian forms have no generic connexion with the true Bajocian Lissocerates. It seems that several lineages within the Oppelidæ developed these smooth, rounded forms, and increased knowledge and more material will doubtless enable us to assign to those later groups, which, wrongly, have been put in the genus *Lissoceras*, their proper places within the family Oppelidæ.

Genus Perisphinctes Waag. *em.* Siem.

Perisphinctes (Groussouvria) cf. regalmicensis (Gemmellaro). (Pl. LIII, figs. 3 *a* & 3 *b*.)

1875. *Ammonites regalmicensis* Gemmellaro, 'Faune Giur. & Liass. della Sicilia' p. 119 & pl. xiv, fig. 3.
[1867. *Ammonites birmensdorfensis* Mœsch, 'Aarg. Jura' Beitr. z. Geol. Karte der Schweiz, No. 4, p. 291 & pl. i, fig. 3.]
1898. J. von Siemiradzki, 'Monogr. Beschreib. der Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv, p. 87 & fig. 4.

The outer whorl of my specimen is somewhat worn, so exact measurements cannot be made; but the umbilicus amounts to probably 55 per cent. of the diameter, and this exceedingly slow character of the coiling, together with the obliqueness of the constrictions, forms the most noticeable feature of my specimen. It resembles in this respect, as well as in its state of preservation and size, the ammonite figured by Gemmellaro; but, according to Siemiradzki, *P. regalmicensis* has flattened sides, whereas the rounded walls of my specimen remind one of *P. birmensdorfensis* Mœsch, although the costation of the latter form is finer. This has also a larger umbilicus (57 per cent.) than *P. regalmicensis* Gemm.; but, on the whole, I am inclined to associate my specimen with the Sicilian form, as the figure given by Mœsch also shews the last constriction to be almost radial instead of being still strongly prorsoradiate.

In *P. navillei* Favre the obliquity of the costæ, and especially of the constrictions, is a still less noticeable feature.

The ammonite is undoubtedly of Argovian age.

Perisphinctes (Grossouvria) cf. navillei Favre.

1875. E. Favre, 'Descr. des Foss. du Terrain Jurass. de la Montagne des Voirons' Mém. Soc. Pal. Suisse, vol. ii, p. 34 & pl. iv, fig. 1.

The identification of this specimen is difficult, owing to its bad state of preservation; but it seems to be closely comparable with Favre's form from the Birmensdorf Beds of Voirons.

At a diameter of 60 millimetres the umbilicus measures 49 per cent., and there are about fifty-five costæ slightly prorsoradiate, but becoming worn near the venter, so that my specimen might even be a *Simoceras*, two forms of this genus (*randenense* and *doublieri*) being very similar.

Perisphinctes birmensdorfensis (Mœsch) has a larger umbilicus (57 per cent.) and a circular whorl-section, as well as closer costation, which latter also distinguishes *P. regalmicensis* Gemm. from my specimen.

The ammonites which A. de Riaz figures as *P. birmensdorfensis* (Mœsch)[1] show at a diameter of 51 mm. only forty-five costæ; according to Siemiradzki, they do not, therefore, belong to Mœsch's

[1] 'Description des Ammonites des Couches à *Peltoceras transversarium* de Trept (Isère)' 1898, p. 27 & pl. x, figs. 6–7.

form. Their section is broader than high, however, and this distinguishes them equally from my ammonite. A. de Riaz's forms may be possibly identified with *Perisphinctes* sp. nov. aff. *birmensdorfensis*, quoted by Siemiradzki[1]; but the number of costæ in the latter seems to be at least fifty at a diameter of 58 mm.

PERISPHINCTES (GROSSOUVRIA) cf. DENSICOSTA Gemmellaro.

1877. G. G. Gemmellaro, 'Faune Giur. & Liass. della Sicilia' p. 200 & pl. xvi, fig. 7.
1898. J. von Siemiradzki, *op. supra cit.* Palæontographica, vol. xlv, p. 89.

A fragment shows the oblique dichotomous costæ as in the type; but the secondaries seem to be more regularly bifurcating, and the two branches pass across the periphery without the strong forward bend. The section also is probably slightly flatter at the sides, and these form more of an angle at the umbilical border.

The type comes from the lower beds of the *acanthicus* zone of Sicily.

There does not seem to be any Argovian form with which my specimen might be more closely connected; but, since I possess only a fragmentary specimen, comparison becomes both difficult and unreliable.

PERISPHINCTES (BIPLICES) KOBELTI Neumayr.

1885. M. Neumayr, 'Geogr. Verbr. d. Juraform.' Denkschr. K. Akad. Wissensch. Wien, vol. l, p. 82 (138) & pl. i, fig. 1.
1907. L. Pervinquière, 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' p. 22 & pl. i, fig. 5.

Two specimens from Sidi Bu Gubrîn seem to agree well with the figures and descriptions given for this form. They show the wide umbilicus of about 50 per cent. of the diameter, a section which is slightly broader than high, and two very deep constrictions on the last whorl. The number of costæ (fifty-five) and their continuity across the venter seem to show that my ammonite is even nearer Neumayr's type than the specimen figured by Pervinquière.

One of the specimens, which seems to have suffered in earth-movements, might possibly belong to an allied Simocerate form, as its periphery is not well preserved.

As I mentioned in the first part of my paper, I am not at all satisfied that the age of this form is 'certainly Tithonian.' Le Mesle has found it with 'Oxfordian' fossils, and its association at Sidi Bu Gubrîn with ammonites the great majority of which belong to the *transversarius* zone does not confirm Pervinquière's view.

Uhlig considers these forms of the *tiziani* group to be true *Perisphinctes*; but, since he omits to state his reasons for not accepting Siemiradzki's classification, and, further, since he does not seem to have made a detailed study of the early Perisphinctoids, I prefer to leave the form here described in the subgenus *Biplices* v. Sutn.

[1] 'Monogr. Beschreib. der Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv (1898) p. 87: *Ammonites colubrinus (pars)* Quenst.

PERISPHINCTES (ATAXIOCERAS) ÆNEAS Gemmellaro.

1877. G. G. Gemmellaro, 'Faune Giur. & Liass. della Sicilia' p. 162 & pl. xx, fig. 12.
1898–99. J. von Siemiradzki, 'Monogr. Beschreib. d. Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv, pp. 184 & 342.
1898. A. de Riaz, 'Descr. des Amm. des Couches à *Peltoceras transversarium* de Trept (Isère)': as *P. virgulatus* (Quenst.) p. 20 & pl. x, fig. 4.

I possess only half an ammonite, measuring about 70 millimetres in diameter; but the fine costation and somewhat flat compressed section make this common fossil of the *transversarius* zone easily recognizable.

Siemiradzki unites De Riaz's ammonite with Gemmellaro's type; but in the latter the costation is certainly much finer and the umbilicus larger—characters in which my specimen comes very near to the type.

PERISPHINCTES (ATAXIOCERAS) cf. MICHALSKII Bukowski.

1898. J. von Siemiradzki, 'Monogr. Beschreib. der Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv, p. 188 & pl. xx, fig. 1.
1898. A. de Riaz ('*P. schilli*') 'Descr. des Amm. des Couches à *Peltoceras transversarium* de Trept (Isère)' p. 33 & pl. xii, fig. 6.

The figures cited above only represent outer whorls, whereas my specimen consists of half a young ammonite measuring not more than 28 mm. in diameter. The section with its greatest thickness near the umbilical border, the amount of evolution, and the character of the prominent costation (showing a very strong hook at the umbilical end of the ribs), seem, however, to agree excellently with this form.

The ammonite occurs in the *transversarius* zone of Niort and Trept, as also in the *cordatus* beds of Czenstochau.

PERISPHINCTES (ATAXIOCERAS) cf. DEPERETI De Riaz.

1898. A. de Riaz, 'Descr. des Amm. des Couches à *Peltoceras transversarium* de Trept (Isère)' p. 19 & pl. x, fig. 1.
1899. J. von Siemiradzki, 'Monogr. Beschreib. der Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv, p. 343.

The small and badly-preserved specimen which I refer to this form agrees very well with De Riaz's figure, but the flexiradiate character of the ornament is not very pronounced. It is, therefore, possible that the ammonite does not even belong to the subgenus *Ataxioceras*, and may in reality form the inner whorls of a true *Perisphinctes*, such as that figured by De Riaz on pl. vii, fig. 4 of the above-cited work (as *P. lucingensis* Favre), which is considered by Siemiradzki to be *P. jelskii* Siem. There is little resemblance to the typical development of the latter form, however, though a true *P. lucingensis* Favre from Chavaz (Savoy) in my collection is considerably nearer. However, since the fact that the peripheral part of my specimen is worn may account for the indistinctness of the flexiradiation, and since in other respects the specimen closely resembles De Riaz's form, I prefer to unite it with that form rather than with the other 'species' mentioned.

Perisphinctes cf. sayni De Riaz.

1898. A. de Riaz, 'Descr. des Amm. des Couches à *Peltoceras transversarium* de Trept (Isère)' p. 18 & pl. xv, fig. 5.
1899. J. von Siemiradzki, 'Monogr. Beschreib. der Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv, p. 309 & fig. 75.

One of my small ammonites agrees with De Riaz's figure, but this represents only the outer whorl of a large specimen.

According to Siemiradzki, the inner whorls have a depressed quadrate section and strong straight costæ, which bifurcate into much weaker branches on the ventral area. My specimen agrees in these particulars very well. Pseudotrifurcation is also shown, and altogether the shell has somewhat the aspect of an annulose *Peltoceras*, or, as De Riaz says, if the costæ did not branch, of *Simoceras*.

My form seems to differ in not having the costæ as close as the type (sixty costæ per whorl, according to Siemiradzki), but this difference might be accounted for by its small size, especially as a fragment of a younger whorl depicted by A. Borisyak[1] shows ribbing of a character exceedingly like that of my specimen.

Perisphinctes cf. jelskii Siem.

1887. *Ammonites convolutus* Quenstedt, 'Ammoniten d. Schwäbischen Jura' pl. xciv, fig. 8.
1898. *Perisphinctes jelskii* Siemiradzki, 'Monogr. Beschreib. d. Ammonitengattung *Perisphinctes*' p. 274 & pl. xxiv, fig. 36 only.

My specimen has unfortunately only the ventral region well preserved, and comparison with the above figures, which represent lateral views, is difficult. The ventral sinus described by the secondary costæ on the periphery and the almost grooved siphonal line are shown in fig. 40 of Quenstedt's pl. xciv. But this form (also called *A. convolutus* by Quenstedt) is referred by Siemiradzki to *P. obliqueradiatus* Yüssen, and in that lineage (*Ataxioceras-lothari* group) no parabolar markings are developed, whereas my specimen shows about six pairs of knobs per half-whorl. It is on account of these parabolar markings that I refer my specimen to *P. jelskii* Siem., a form in which the young whorls have a similar depressed section, with strong prorsiradiation and constrictions.

P. jelskii Siem. occurs in the *transversarius* zone of Poland, Swabia, and France.

Perisphinctes plicatilis De Riaz (*non* Sow. *nec* Siem.).

1898. A. de Riaz, 'Descr. des Amm. des Couches à *Peltoceras transversarium* de Trept (Isère)' p. 9 & pl. iii, figs. 1–4.
1899. J. von Siemiradzki, 'Monogr. Beschreib. der Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv, p. 343.

One specimen, consisting of about three-quarters of an ammonite

[1] 'Fauna des Donez-Jura: I—Cephalopoda' Mém. Com. Géol. Russie, n. s. No. 37, 1908: '*P. sayni*, de Riaz' p. 75 & pl. vi, fig. 1, pl. ii, figs. 15–17.

measuring 36 mm. in diameter, agrees with De Riaz's figure in the obliqueness of the costation and constrictions, the flattened sides, and the distinct umbilical rim. Unfortunately, the ammonite is worn, and therefore the identification must remain doubtful.

Another larger ammonite, 55 mm. in diameter, has its outer whorl somewhat worn, but seems to agree in all details (except in its thin section) with the ammonites figured by A. de Riaz in his pl. iii as *P. plicatilis* Sow.

In section, the specimen would agree more with *P. obliqueplicatus* Waagen, as figured in Siemiradzki's pl. xxii, fig. 23 *a* and text-fig. 2, p. 84. But the costation is not oblique enough here.

The ammonite figured by De Riaz as *P.* cf. *obliqueplicatus* Waag. (pl. xv, fig. 4) has the costæ too distant; Siemiradzki regards it as a new form '*P. bifurcatus*,' but gives no figure of the section.

Since my specimen is not well enough preserved, I prefer to leave it with the equally indefinite Trept forms. Siemiradzki unites all the four ammonites (which, it may be mentioned, differ somewhat one from the other) with his '*plicatilis* (Sow.) d'Orb.' from the 'Lower Oxfordian,' and this makes me adopt the above designation for the Argovian forms.

Perisphinctes cf. convolutus (Quenst.).

1888. F. A. von Quenstedt, 'Ammoniten d. Schwäbischen Jura' *convoluti* (pars) pl. xciv, figs. 20 & 43.

1898. A. de Riaz, 'Descr. des Amm. des Couches à *Peltoceras transversarium* de Trept (Isère)' (*P. convolutus* Quenst.) p. 19 & pl. ix, figs. 5 *a* & 5 *b*.

1899. J. von Siemiradzki, 'Monogr. Beschreib. der Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv, p. 341.

My small ammonite probably corresponds with the inner whorls of a convolute *Perisphinctes* similar to that figured by De Riaz, and seems to be somewhat intermediate between figs. 20 and 43 of Quenstedt's pl. xciv. It is very finely costate, with a broad flat venter, forming an angle with the sides, and shows about seven fine constrictions per whorl. At a diameter of 13·5 mm. its thickness is about 55 per cent. and the height of the last whorl 33 per cent., whereas De Riaz's form has, at an equal percentage of height, a thickness of only 46 per cent.; but the diameter is here much larger.

Pervinquière[1] mentions under *Holcostephanus* cf. *celsus* (Opp.) an ammonite from the red limestone of Jebel Ben Saidan, and this seems to be distinguished from the form here described only by a coarser costation and fewer and wider constrictions, if we assume it to resemble in this respect the specimen figured by him from a different locality. *Spiticeras proteanum* (Zitt. *non* Opp.) = *Sp. celsum* (Opp.), also bears some resemblance in its inner whorls[2] to the form now described; but the different character of the constrictions

[1] 'Études de Paléontologie Tunisienne: I—Céphalopodes des Terrains Secondaires' 1907, p. 41 & pl. ii, figs. 9–10.

[2] K. A. von Zittel & A. Oppel, 'Die Cephalop. der Stramberger Schichten' Pal. Mitt. Mus. K. Bayer. Staates, vol. ii, pt. 1 (1868) p. 90 & pl. xvi, fig. 2 *b*.

and costation distinguishes these later forms. My ammonite does not seem to be a *Holcostephanus*; as the innermost whorls, however, are not shown, it is impossible to make a definite statement on this point.

Siemiradzki calls A. de Riaz's form a '*mutatio descendens*' of *P. (Grossouvria) mirus* Bukowski from the *cordatus* zone of Poland. My specimen may belong to that group of Siemiradzki's *Grossouvria*, but its many constrictions separate it from *P. mirus* itself.

PERISPHINCTES sp. nov., aff. TRICHOPLOCUS Gemm. (Pl. LIII, fig. 4.)

1877. G. G. Gemmellaro, 'Faune Giur. & Liass. della Sicilia' p. 163 & pl. xx, fig. 13.
1898. J. von Siemiradzki, 'Monogr. Beschreib. der Ammonitengattung *Perisphinctes*' Palæontographica, vol. xlv, p. 273.

I have not been able to find the description of any ammonite more comparable with my specimen than Gemmellaro's form.

My specimen differs, however, in having a larger umbilicus (about 50 per cent. at a diameter of 70 mm. instead of 45 per cent.) and also a larger number of single costæ. Siemiradzki says that single costæ are not frequent, and, as a matter of fact, Gemmellaro's figure shows among eleven costæ on the last whorl three single ones; but in my specimen there are from two to three single ribs between each bifurcating pair, a feature that brings the ammonite very near to certain Simocerates. At a diameter of 60 mm., however, the costæ still pass uninterruptedly across the venter, and it is only on the last half of the outer whorl that the sinus, which is formed on the periphery by the meeting of the secondaries, becomes clearly broken in the siphonal line.

In whorl-section my specimen agrees with Gemmellaro's form, the height from the umbilical junction being a little larger than the width. Only one constriction is visible on my specimen, owing to the umbilicus being partly covered by matrix; but it is comparatively broad, as figured by Gemmellaro, and not narrow and shallow as Siemiradzki mentions.

Genus PELTOCERAS Waag.

PELTOCERAS TOUCASIANUM (d'Orb.). (Pl. LII, figs. 5 *a* & 5 *b*.)

1847. A. d'Orbigny, 'Pal. Franç.: Terr. Jurass.—Céphal.' p. 508 & pl. cxc.
1871. M. Neumayr, 'Jurastudien: 4—Vertretung der Oxfordgruppe, &c.' Jahrb. K.K. Geol. Reichsanst. vol. xxi, p. 368 & pl. xix (xx), fig. 1.
1877. G. G. Gemmellaro, 'Faune Giur. & Liass. d. Sicil.' p. 166 & pl. xx, fig. 17.

The dimensions of my specimen are as follows:—

Diameter	53 millimetres.
Height of the last whorl	36 per cent. of the diameter.
Thickness of the last whorl	33 per cent. of the diameter.
Umbilicus	40 per cent. of the diameter.

Oppel united Quenstedt's *Ammonites transversarius* with A. d'Orbigny's form, and Neumayr followed him, although he pointed out that the two ammonites did not quite agree. Neumayr considered, however, that the differences were only apparent, and that

they were due to different age, in so far as the specimens from Central European localities generally were of smaller dimensions than those of Mediterranean origin. He stated that, with increase in diameter, the umbilicus widened, and that the sides sloped less steeply towards the ventral margin : that is, that in the adult *Peltoceras transversarium* changed into *P. toucasianum*.

After being separated again by A. de Riaz,[1] the two forms were once more united by P. de Loriol,[2] who considered the occurrence of a number of transitional forms as proof of their close affinity, and who, moreover, regarded Quenstedt's type-figure as representing an exceptional variety. Dr. H. Salfeld,[3] who in 1906 renewed the discussion of the identity of the two forms, has been able to demonstrate, however, the correctness of Quenstedt's original drawing,[4] and has refigured the type of *transversarius*, together with additional specimens.

There can be no doubt that A. d'Orbigny's *P. toucasianum* can clearly be distinguished from Quenstedt's form, even if we do not accept Dr. Salfeld's interpretation of the former in its entirety. In the true *P. toucasianum* the ribs are sigmoidal and strongly rursiradiate; in *P. transversarium* they are simply curved backwards, even in the young. According to Dr. Salfeld[5] also, the periphery broadens in the adult *P. toucasianum*, whereas in *P. transversarium* the narrowing of the periphery is a fairly constant feature, which is the reverse of what Neumayr had believed to be the case.

If we consider the costation only, the change from one form into the other also seems to take place the other way about : that is, rather from *P. toucasianum* into *transversarium* than *vice versâ*, and we may, with Dr. Salfeld, therefore regard *P. toucasianum* as the Mediterranean ancestor of the Birmensdorf form.

A. d'Orbigny's ammonite, at a diameter of 75 millimetres, has the following dimensions :—

Umbilicus..........................	39 per cent. of the diameter.
Height of the last whorl............	34 per cent. of the diameter.

Gemmellaro's specimen, at 67 mm. diameter, shows :—

Umbilicus............................	41 per cent. of the diameter.
Height of the last whorl............	34 per cent. of the diameter.

My slightly smaller specimen is almost equal in dimensions, and for larger proportions the specimen of '*Perisphinctes*' *transversarius*

[1] 'Description des Ammonites des Couches à *Peltoceras transversarium* de Trept (Isère)' 1898, p. 54.

[2] 'Oxfordien Supérieur & Moyen du Jura Lédonien' Mém. Soc. Pal. Suisse, vol. xxx (1903) p. 103.

[3] 'Beitrag z. Kenntnis des *Peltoceras toucasi* (d'Orb.) & *P. transversarium* (Quenst.)' N. Jahrb. vol. i (1906) p. 81.

[4] F. A. von Quenstedt, 'Cephalopoden' 1849, pl. xv, fig. 12 & p. 199; and 'Ammoniten d. Schwäbischen Jura' 1888, pl. xci. fig. 26 & p. 830.

[5] *Op. supra cit.* p. 87, footnote.

from Torri, Lake of Garda (Neumayr, pl. xix, fig. 1), at 110 mm. diameter shows:—

Umbilicus	42 per cent. of the diameter.
Height of the last whorl	33 per cent. of the diameter.

Quenstedt's type of *transversarius*, on the other hand, at 45 mm. diameter has:—

Umbilicus	35·5 per cent. of the diameter.
Height of the last whorl	40 per cent. of the diameter.

The largest figured specimen of a true *transversarius* (figs. 7 *a* & 7 *b* of Salfeld) is only fragmentary, and comparison of measurements in the adult is, therefore, impossible; but the persistence of the close, slightly curved rursicostæ and the trapezoidal section are still very characteristic.

Neumayr's fig. 1 *a*, at a diameter of 70 mm., represents the peculiar sigmoidal curvature of the costæ, which, as well as being so conspicuous a feature of A. d'Orbigny's type, is well shown in Gemmellaro's figure and is also very distinct on my specimen. It is absent, so far as I am aware, in all the other specimens of '*toucasianum*' or '*transversarium*' figured, and in my opinion clearly distinguishes A. d'Orbigny's form from its descendant, although it remains to be investigated whether the branching of the costæ may permit us to recognize several varieties of *Peltoceras toucasianum.*

The form is characteristic of the *transversarius* zone of the Mediterranean Middle Corallian, and occurs throughout the Alpine 'geosyncline,' from the Carpathians to Sicily and the range of the Atlas.

PELTOCERAS cf. TOUCASIANUM (d'Orb.).

1906. *Peltoceras toucasi* (d'Orb.) Salfeld, 'Beitrag z. Kenntnis des *Peltoceras toucasi* (d'Orb.) & *Peltoceras transversarium* (Quenst.)' Neues Jahrb. vol. i (1906) p. 81 & pl. x, fig. 4 only.

My collection contains only a septate whorl-fragment 21 mm. high, agreeing fairly in ornament with the figure cited above. The costæ are simply curved backwards, and form rather strong points at the latero-peripheral angles. The side of the whorl is slightly concave, but the section seems to be distinguished by a broader periphery than is shown, for example, in Salfeld's pl. x, fig. 3 *b*. My specimen is too fragmentary, however, to enable me to make a closer comparison.

I may add here that the latero-peripheral angle of the costæ is situated in the middle of the outer branch of the external saddle (which is subdivided by a lobule), whereas in whorl-fragments which I refer to the forms described below the end of the costæ comes close to the lobule. Thus here the saddle still goes some distance across the venter, showing a broader periphery corresponding with a lower umbilical rim. The whole of the suture is not preserved, unfortunately, in any of my specimens.

The ammonite is neither *P. toucasianum* nor *P. transversarium*,

but represents one of those intermediate forms which seem to be the commonest, and to which, for instance, besides Quenstedt's figs. 21 & 29, the figures of P. de Loriol,[1] those of A. de Riaz,[2] and also some of Dr. Salfeld's *P. toucasi* (as, for example, his fig. 3 of pl. x) belong. Fig. 27 of Quenstedt's pl. xci [3] represents neither an old *toucasianum* nor an old *transversarium*, but a densicostate fragment of an undetermined variety. With the scanty material at my disposal I refrain from naming these varieties.

PELTOCERAS PERVINQUIÈRI, nom. nov. = P. FOUQUÉI Perv. *non* Kil.

1907. L. Pervinquière, 'Études de Paléontologie Tunisienne : I—Céphalopodes des Terrains Secondaires' p. 28 & pl. i, fig. 9.
non 1877. G. G. Gemmellaro, 'Faune Giur. & Liass. della Sicilia' p. 166 & pl. xx, fig. 16.
non 1889. W. Kilian, 'Mission d'Andalousie : II—Études paléontologiques sur les Terrains Secondaires & Tertiaires de l'Andalousie' Mém. Ac. Sci. Paris, vol. xxx, p. 631 & pl. xxvi, fig. 2.

Dr. Kilian's figure shows, at a diameter of 90 mm., an umbilicus measuring 43 per cent. and height of the last whorl 38 per cent. It is only the last three-quarters of the final whorl that are radially recticostate. Before then, the ribs are close, slightly rursicostate, and, finally, seem to be of the usual *toucasianum* type. Gemmellaro's form, at a diameter of 150 mm., has an umbilicus measuring 43 per cent. also, and the height of the last whorl equals 35 per cent. The inner whorls are badly preserved, but apparently similar to those of Dr. Kilian's ammonite.

Now, the specimen which Pervinquière identifies with Dr. Kilian's form has an umbilicus of only 38 per cent., not 43 per cent.; but, what is more important, the exceedingly coarse and distant costation is essentially radial and straight already at a very small diameter. It probably forms the final development in that direction, and certainly has a good claim to be separated from *P. fouquéi* Kil.

The ammonite figured by Dr. Salfeld as a large specimen of *P. toucasianum* from Palermo [4] closely resembles Gemmellaro's form (fig. 16 only), but its dimensions are, at a diameter of 115 mm.:—

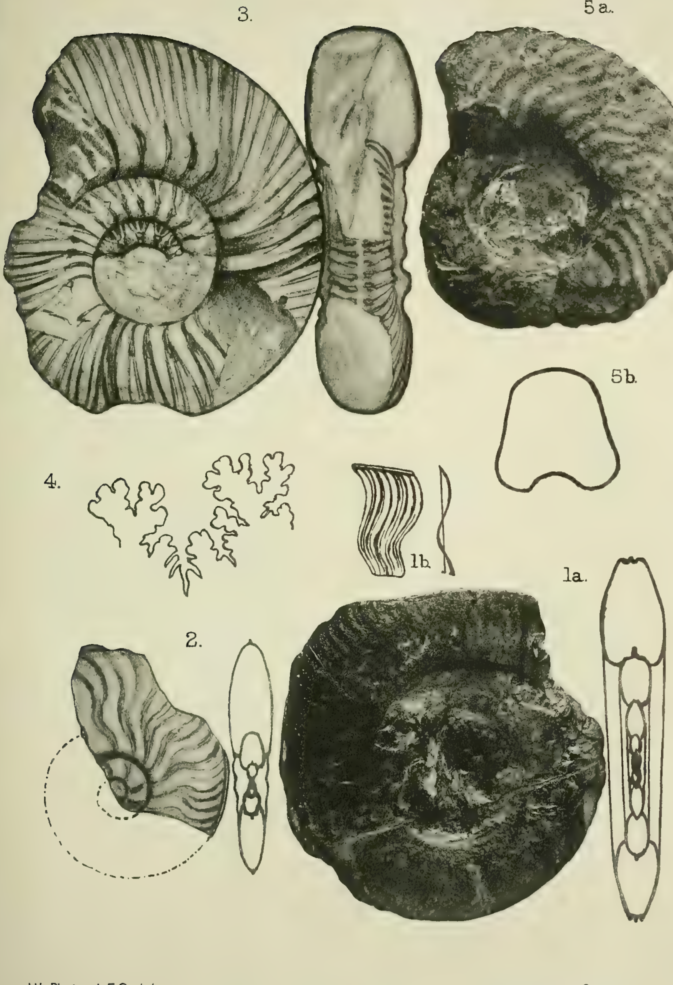
Umbilicus	38 per cent. of the diameter.
Height of the last whorl............	36 per cent. of the diameter.

Similarly, a cast in my collection, taken from a specimen from Mœnthal (Switzerland), shows at a diameter of 120 mm.:—

Umbilicus	39 per cent. of the diameter.
Height of the last whorl............	37 per cent. of the diameter.

It is equally recticostate on the last whorl. These two forms would, then, represent an involute variety of *P. fouquéi* Kil.; but the study of the inner whorls of the ammonites belonging to this

[1] *Op. cit.* Mém. Soc. Pal. Suisse, vol. xxx (1903) pl. xv, figs. 5 & 6.
[2] 'Description des Ammonites des Couches à *Peltoceras transversarium* de Trept (Isère)' 1898, pl. xix, figs. 1–4.
[3] 'Ammoniten d. Schwäbischen Jura' 1888.
[4] *Op. cit.* N. Jahrb. vol. i (1906) pl. xii, fig. 11.



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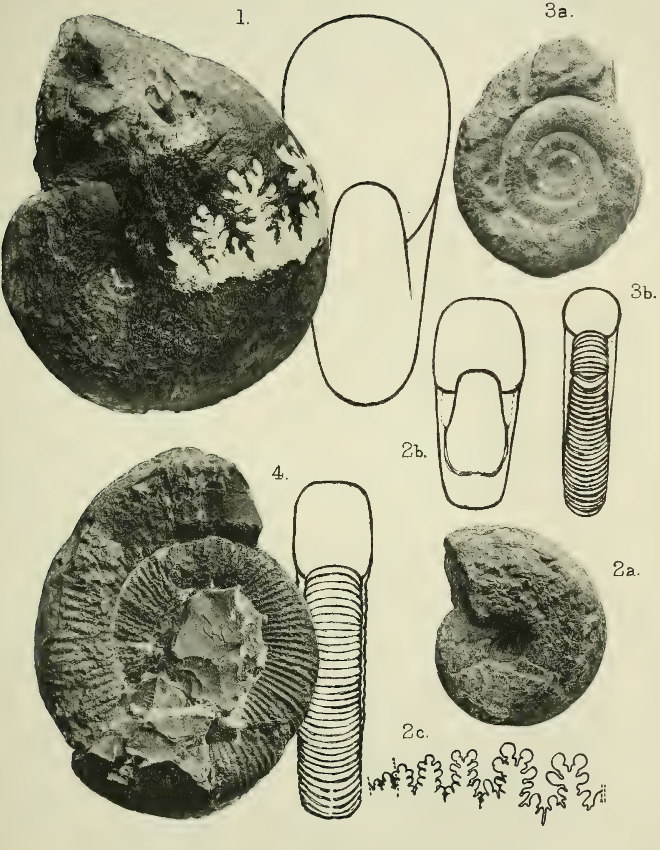
AMMONITES FROM JEBEL ZAGHUAN.



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AMMONITES FROM JEBEL ZAGHUAN.

group becomes an absolute necessity if the specific distinction of *P. fouquéi* from *P. toucasianum* is to be definitely established. Taking Neumayr's fig. 1 of pl. xix as an example of a large *P. toucasianum*, we notice that the costæ are not yet radial at the end, and it appears that *P. fouquéi* is distinguished only by an earlier appearance of subrecti- and then recticostation. In all forms of *P. fouquéi* the section is very nearly rectangular.

I have to describe here two fragments of chambered whorls, measuring respectively 18 and 16 mm. in height. The first agrees in its perfectly straight and radial costation, low umbilical edge, and flat sides with Pervinquière's figure. The second has its costæ slightly curved, but shows a low umbilical rim and otherwise close agreement, though it might possibly more correctly be included in *P. fouquéi*.

The occurrence of all these forms together at Sidi Bu Gubrîn is a significant fact. I am inclined to think that not only *P. toucasianum*, the *transversarium*-like forms, and their close ally *P. fouquéi*, but also *P. pervinquièri* occur in Argovian deposits. The latter two may have persisted at least in *bimammatum* times; this would account for their occurrence in the *transversarius* zone of Algeria and Sicily, and in higher beds in Andalusia and elsewhere.

Genus Aspidoceras Zittel.

Aspidoceras cf. ægir (Opp.).

1863. A. Oppel, 'Ueber Jurass. Amm.' Pal. Mitt. Mus. d. K. Bayerisch. Staates, p. 226 & pl. lxiii, fig. 2.
1871. M. Neumayr, 'Jurastudien: 4—Vertretung der Oxfordgruppe, &c.' Jahrb. K.K. Geol. Reichsanst. vol. xxi, p. 372 & pl. xx, fig. 2, pl. xxi, fig. 2.

I refer, with some hesitation, a small specimen of *Aspidoceras* to this form, because the latter is so common a fossil in the *transversarius* zone and has also been recorded (by Baltzer) from Jebel Zaghuan before. As Oppel points out, it is distinguished from what has generally been considered on the Continent as *Aspidoceras perarmatum* (Sow.) by flatter sides and the earlier appearance of the umbilical tubercles; but, at the diameter of my specimen (about 18 mm.), which, besides, is not very well preserved, distinction from other similar Aspidocerates is impossible.

In its quadrate section the ammonite in question also resembles *Aspidoceras faustum* Bayle[1] and *A. ruppelense* (d'Orb.), as figured in the 'Paléontologie Française'[2] and by Thurmann[3]: in the adult, only, however. The young of the latter ammonite is much too spinous, and in *A. faustum* the inner whorls are smooth, not costate.

Certain small ammonites in my collection from the Ampthill Clay of St. Ives (Huntingdon), which I have referred to *A. babeanum* (d'Orb.), seem to be distinguished from the Tunisian ammonite

[1] 'Expl. Carte Géol. France' vol. iv (1878) pl. xlvii, fig. 1.
[2] 'Terr. Jurass.—Céphal.' p. 538 & pl. ccv, fig. 2.
[3] J. Thurmann & A. Etallon, 'Lethæa Bruntrutana' 1861, p. 78 & pl. ii, fig. 8.

only by a wider and more rounded peripheral region, but probably represent exactly the same horizon.

EXPLANATION OF PLATES LII & LIII.

Plate LII.

(All figures, except fig. 4, are of the natural size.)

Fig. 1 *a*. *Protogrammoceras cornacaldense* (Tausch), var. *zeugitanum* nov. Middle Lias (Domerian), Poste Optique, Jebel Zaghuan. 1 *b*. Ornament of last whorl, where not weathered. (See p. 552.)

2. Gen. nov. sp. nov. (aff. *Lioceras ? grecoi* Fucini). Middle Lias (Domerian), from the same locality. (See p. 556.)

3. *Reineckeia* aff. *hungarica* Till. Callovian, from the same locality. (See p. 558.)

4. *Perisphinctes* cf. *bieniaszi* Teisseyre. Callovian, same locality. Part of suture enlarged. (See p. 560.)

5 *a*. *Peltoceras toucasianum* (d'Orb.). Argovian (zone of *Peltoceras transversarium*), near Sidi Bu Gubrîn, Jebel Zaghuan. 5 *b*. Outline-section of the last whorl. (See p. 575.)

Plate LIII.

(All figures, except fig. 2 *c*, are reduced to four-fifths linear.)

Fig. 1. *Phylloceras* cf. *subptychoicum* Dacqué. Argovian. Near Sidi Bu Gubrîn, Jebel Zaghuan. (See p. 562.)

2 *a*. *Sowerbyceras protortisculatum* (Pompeckj). Argovian. Same locality. 2 *b*. Peripheral view, partly restored. 2 *c*. Suture-line, magnified. (See p. 565.)

3 *a*. *Perisphinctes (Grossouvria)* cf. *regalmicensis* (Gemm.). Argovian. Same locality. 3 *b*. Peripheral view, partly restored. (See p. 570.)

4. *Perisphinctes* sp. nov., aff. *trichoplocus* Gemmellaro. Argovian. Same locality. (See p. 575.)

Discussion.

Mr. Buckman heartily congratulated the Society on the paper which they had just heard. The Author showed rare ability in his knowledge of ammonites, and was evidently working on what the speaker considered to be the right lines. The Author had shown that he possessed a full grasp of his subject; and the speaker could not help feeling pleased at the able use which the Author made of a terminology for which he (the speaker) was so largely responsible. The Author seemed to have a more intimate acquaintance with the terms than the speaker had himself, and this was an agreeable surprise.

The Author, in reply, thanked the President and Fellows for the kind and interested way in which they had received his paper, and Mr. Buckman for his encouraging words.

With regard to the fitness of the new generic term *Protogrammoceras*, the Author thought that if the Hildoceratidæ were a monophyletic family, the ancestral forms of the Toarcian genera would have to be looked for in the Domerian predecessors and, therefore, probably in the far too comprehensive genus *Protogrammoceras*. Since not relationship but external resemblance to the later *Grammoceras* was chiefly referred to, however, when choosing *Protogrammoceras*, the Author agreed with Mr. Buckman in considering that a non-descriptive term might preferably have been adopted.

26. *On* the Age *of the* Suffolk Valleys; *with* Notes *on the* Buried Channels of Drift.

By Percy George Hamnall Boswell, A.R.C.S., B.Sc., F.G.S. (Read May 28th, 1913.)

[Plates LIV & LV—Maps.]

Contents.

I. Introduction.

The main watershed of Suffolk follows generally the Chalk outcrop, but keeps rather to the east of it, running in a north-easterly direction from Haverhill, in the south-west of the county, to Diss, on the borders of Suffolk and Norfolk, where it turns north, or a little west of north, until it finishes at the Cromer ridge. It thus runs roughly parallel to the Chalk escarpment, changing in direction with it. This more easterly run of the watershed appears to be due to the covering of Glacial Drift upon the Chalk. The valley-system of Suffolk is, in consequence of this change of strike of the Chalk and change of direction of the main watershed, of a palmate or radiating form, the rivers which have carved the chief valleys, taken from north to south, being:—(1) The Waveney, flowing east-north-eastwards and entering the North Sea at Yarmouth; (2) the Alde, flowing generally east-south-eastwards to Aldeburgh, but only reaching the sea at Orford; (3) the Deben, flowing south-eastwards to the coast at Bawdsey; (4) the Gipping (with its estuary, the Orwell), also flowing south-eastwards; (5) the Brett, flowing southwards into the Stour estuary; and (6) the Upper Stour (as distinct from the Stour estuary), flowing southwards into the wide east-and-west estuary of the same name.

The Little Ouse, rising close against the source of the Waveney at Lopham Ford (where a small low bank of gravel forms the only present watershed), flows westwards, and forms part of the northern county boundary. At Thetford it receives a small tributary flowing from the south-east through Ixworth and Euston. The Lark, on which stands Bury St. Edmund's, is the only other

stream of any size in Suffolk flowing north-westwards into the Wash basin (see map, Pl. LIV).

The western part of the county lies within the area of the Chalk outcrop; but, as we travel eastwards, this formation is seen to dip at about 15 feet to the mile, and is successively overlain by Eocene beds (Thanet Clays & Sands, Woolwich & Reading Beds, Oldhaven Beds?, and London Clay) and by the East Anglian Crags (Red and Coralline Crag in the south, Norwich Crag and Chillesford Crag, etc. in the north). However, the whole country is more or less plastered over with a thick mantle of Glacial Drift, and therefore the so-called 'solid geology' is revealed only in the deeper and more important valleys.

The Drift consists of:—(*a*) The Lower Boulder Clay (that is, the Contorted Drift or Norwich brickearth), continuous with that deposit in Norfolk, occurring in the northern part of the county only.

(*b*) The series of beds of sand, gravel, and loam (brickearth), which underlie the Upper Boulder Clay (*c*), and were conveniently grouped with other gravels of different ages by the Geological Survey under the general term 'Middle Glacial' of S. V. Wood, Jun. The gravels are usually 'clean' (that is, not loamy or much iron-stained), horizontally or current-bedded, and show marked selective deposition in the matter of the size of their constituent pebbles. The term 'shingle' is frequently applied to them in well-borings. They are largely composed of much altered and waterworn, opaque, red and brown flint, together with vein-quartz, sandstones, and quartzite (Bunter pebbles and sarsens); also, less commonly, Jurassic débris and igneous or metamorphic rocks. The sands are sharp, clean, quartzose, and often highly current-bedded. They are white, yellow, pale brown, or red, and generally coarse, the last feature usually serving to distinguish them from the Reading Sands that occur in the area. The loams or brickearths are, as a rule, buff or blue, and are very homogeneous and finely laminated. Less commonly they contain big flints and Jurassic fossils and boulders. Experiments have shown that precisely similar material has resulted from washing the Upper Chalky Boulder Clay free of rock-fragments and allowing the sediment to settle. Indeed, this process is carried out in several brickfields to obtain a pure 'earth' from the Boulder Clay for the manufacture of white bricks. The loams are thus clearly outwashed from the Upper Boulder Clay, and they occur in lake-like patches scattered over the county.

(*c*) The Upper Boulder Clay, part of the Great Chalky Boulder Clay of S. V. Wood, Jun., which covers East Anglia and the Midlands. Mr. Harmer has recognized two distinct types in Suffolk: the Chalky Boulder Clay of the western and south-western portions; and the Chalky-Kimeridgic Boulder Clay which forms the high land of Suffolk, and covers the east and south-east of the county.

(*d*) A series of gravels that lie above the Upper Boulder Clay, and are referred to in this paper, for the purpose of distinction,

as 'glacieluvial gravels.'[1] These are usually high-level gravels occurring up to 250 feet O.D., but are sometimes found extending down into the valleys. There are two types, one of which is sometimes seen to overlie the other (as at Woolpit). One is an intensely chalky gravel, often associated with chalky sand and occasionally bedded at a high angle, containing chiefly pebbles of Chalk and Jurassic fossils, with some flint. The other type, which forms larger masses, is a highly-ferruginous flinty gravel, devoid of any signs of bedding, with a loamy matrix. The bed frequently contains twisted wisps of loam and Chalky Boulder Clay. The flints are often large, with the same irregular shape as that which they possess in the Chalk, but bearing evidence in their crust (especially upon knob-like projections) of very great battering. Many are broken or angular, and nearly all are fresh, black or dark-brown, translucent, unaltered flint. There has been no sorting into sizes—large and small flints and, less commonly, other rocks forming a higgledy-piggledy mixture. The flints occur in all positions, many being set up on end. Usually 12 to 14 feet of this deposit is the maximum thickness, and exposures are met with at Drinkstone, Tostock, Woolpit, and Elmswell, near Bury St. Edmund's, Newton and Great Waldingfield near Sudbury, Creeting, Barking, Rushmere, and Ipswich in the Gipping Valley, and other places. They were probably the final result of the glaciation of the district, left sporadically by torrential streams on the recession of the ice. Their formation is thus somewhat similar to that of the 'Cannon-Shot' Gravels of Norfolk, described by Mr. F. W. Harmer; and, but for the fact that their constituent boulders are not beautifully rounded like those in some of the occurrences of the 'Cannon-Shot' Gravels, they find their closest parallel therein.

In addition to the Drift deposits described above, sands and gravels, and, more rarely, loams occur, forming river-terraces.

The object of the following notes is to show that the Suffolk valley-system—at any rate, in its main features—is more recent than the late Pliocene deposits, but older than the Upper Boulder Clay of the area under consideration. In no way can the chief valleys be regarded as of post-Glacial age.

One of the few references to the valley-system of Suffolk, and

[1] [For want of a better term, I have previously referred to these gravels as 'morainic.' Prof. J. W. Gregory, after a visit to East Anglia with Mr. G. Slater and myself, has drawn my attention to the term 'glacieluvial' proposed by him ('The Polmont Kame' Geogr. Journ. vol. xl, 1912, p. 169; 'The Polmont Kame, & on the Classification of Scottish Kames' Trans. Geol. Soc. Glasgow, vol. xiv, pt. 3, 1912, p. 199) for such glacial deposits which are colluvial, to use Merrill's classification, rather than alluvial. There is need for such a term in East Anglian glaciology, as the gravel-deposits under consideration are not fluvio-glacial, for they occur in broad spreads formed by an irregular wash of water down a slope, and not by streams; they are not morainic, for their material appears to have been deposited by water.—*P. G. H. B., Dec. 13th, 1913.*]

perhaps the earliest, is that of Sir J. B. Phear,[1] who, writing in 1854, quaintly says that the Gipping Valley originated as a fracture of the Chalk, with elevation after the Drift Clay (= Upper Boulder Clay) was deposited, the idea being rather reminiscent of Von Buch's volcanic 'elevation' theory. He supposes that the sand cliffs on the valley-sides were due to marine action when the land was subsequently submerged. As a proof of this elevation and fracture, he quotes the case of that little tributary valley of the Gipping which contains Offton, Somersham, and Blakenham villages, and runs roughly west and east. He notes that Chalk is quarried at Offton, where the upper part of the small valley runs south-eastwards. The pit, which is on the north side of the depression, shows Chalk dipping north-eastwards or rising south-westwards. At the Blakenham pits he notes a dip to the north or rise to the south, but does not say on which side of the valley, north or south, the sections are. (There are large pits now on both sides of the stream.) This, he says, proves his contention as to the origin of the valley by fracture and upheaval. Rolls in the Chalk are very uncommon in Suffolk, but it is noteworthy that there is distinct local folding in the large chalk-pit half-a-mile east-south-east of Little Blakenham Church. Possibly Sir J. B. Phear was misled by such a fold. However, he noted that the Chalk area on the north-west formed the chief watershed of the county, and had a south-west to north-east strike, so that the Gipping, flowing in a south-easterly direction, was a dip-stream. He was right in his last observation, but not in the age which he assigned to the formation of the valley.

Wood and Harmer, in their numerous papers descriptive of the East Anglian Glacial deposits, frequently illustrated their remarks with sections drawn across the valleys, mainly those of Norfolk. It was clear that they had noted the frequent occurrence of the Chalky Boulder Clay as a deposit which extended down into and partly filled certain valleys.[2] Mr. F. W. Harmer has kindly forwarded to me two MS. sections, one across the Gipping Valley near Stowmarket (Section 8), the other near Ipswich (Section 9), shown before the British Association Meeting at Norwich in 1868, by S. V. Wood, Jun., and himself. These sections, together with that marked 'P' in the third volume of 'The Crag Mollusca' (Palæont. Soc. Monogr. 1872-74), show Chalky Boulder Clay lying in the valleys. The following is an extract from the (unpublished) manuscript of the paper read to the Meeting of the British Association at Norwich:—

> 'Section 7 shows such a case at the East Suffolk Junction near Ipswich in the Gipping Valley, in which this description of denudation is so sharp that the Red Crag and overlying sands are cut off entirely within the width of an ordinary railway-cutting. Section 8 shows a similar case higher up the same valley at Stowmarket.'[3]

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[1] Sir J. B. Phear, 1856 (1). Numerals in parentheses refer to the Bibliography, § VIII, p. 617.

[2] Harmer, 1867 (2) pp. 87–90; Wood & Harmer, 1869 (4) p. 259.

[3] See p. 592.

II. The Earlier Limit of Age.

Suffolk consists of a plateau-type of country sloping south-eastwards from a culminating height of a little over 400 feet O.D. near Chedburgh, 6 miles south-west of Bury St. Edmund's, and forming a series of low cliffs on the coast. The greater part is at an elevation of 100 to 200 feet O.D., and the plateau is much cut up by a large number of streams tributary to the rivers already mentioned. Most of these excavations into the plateau are totally out of proportion to the quiet meandering brooks which now occupy them. The sides have generally a low gradient (1 in 40 or 50), with the result that the broad valleys expose the Pliocene, Eocene, and Chalk strata under the mantle of Drift. An idea of the gradient is obtained when it is seen, for example, that the London Clay (some 30 feet or less thick) in the southern valleys gives an outcrop measuring nearly a mile in width.

The Waveney Valley cuts down through the Contorted Drift and Crag Beds to the Chalk, sections exposed at various points showing that the valley is therefore later in age than the Contorted Drift.[1] The series of small streams between the Waveney and the Alde, and also the latter river itself, cut through the Crag Beds (Chillesford Beds and Norwich Crag), and on direct evidence are of post-Pliocene age. The Deben flows in a valley which exposes chiefly Red Crag and London Clay, while the Gipping, Brett, and Stour valleys are excavated through Red Crag, London Clay, and Lower London Tertiaries into the Chalk. Exposures of the Lower Boulder Clay or Contorted Drift have been described from time to time as occurring in the southern half of Suffolk, but I am of opinion that it does not extend so far south. It was described by Wood & Harmer as cropping out in the form of mounds through the so-called 'Middle Glacial Sands.'[2] S. V. Wood, Jun., held the view that it underlay parts of the high land of Suffolk; but of this there is no evidence whatever, either in the field or from borings. (Mr. Harmer tells me that he was never quite satisfied about several of the recorded occurrences.) The consideration of most of the localities is not necessary here, but it is clear that the majority of the exposures are in the brickearths, which lie usually as lenticular masses in basins of the sand and gravel, and thus are younger, being probably connected with the 'wash-out' waters from the oncoming ice-sheet which produced the Upper Boulder Clay. The officers of the Geological Survey were usually disinclined to commit themselves to any definite statement regarding the age of these loams; but in a few cases, as, for example, the consideration of certain loams occurring on valley-flanks near

[1] At the brickfield, 1 mile south of Beccles, at 100 feet O.D., 30 feet of Chalky-Kimeridgic Boulder Clay overlies 25 feet+ of Contorted Drift, separated by a few feet of sand. East of the town the Upper Boulder Clay rests in the valley on Chillesford Beds at less than 30 feet O.D. See also F. W. Harmer, 1910 (29) p. 130.

[2] Wood & Harmer, 1877 (7) p. 80.

Woodbridge and Aldeburgh, S. V. Wood, Jun.'s determination was adopted.[1] The fact that the loams were much contorted may have lent colour to this view, but investigation of the section and careful mapping of the area show that these loams are underlain by the sand and gravel series. At the famous Hasketon section (the brickyard a mile north-west of Woodbridge) there is a bed of blue laminated loam, sometimes contorted, overlain by Upper Boulder Clay (Chalky-Kimeridgic), with a continuous passage up in one part of the brickfield. The colour of this blue loam is apparently a direct result of its being wash-out material from the Boulder Clay, which has a deep bluish Kimeridgic matrix. A digging in the floor of the pit reached Glacial sand, which is also met in wells near by, and crops out at its normal lower level in the plantation and sides of the little valley on the west. Between the blue loam and the sand is a bed of reddish and buff-coloured loam with an irregular upper surface. At Blaxhall, near Aldeburgh, are several pits (one figured in the Memoir quoted[2]), which show sands, loams, and chalky material very much mixed up. The consideration of these disturbances follows in a later section of this paper; but it is clear, in this case, that the loams are merely derived from the Upper Boulder Clay, and in places are seen passing into it, and also into the silty and chalky sands so common at this locality. One other exposure calls for comment: namely, Derby Road Brickfield, west of Ipswich, almost on the edge of the Gipping Valley. Here it was recently proved by digging that the brickearth was actually resting on the Upper Boulder Clay, the whole lying in a lake-like basin in the Glacial Sands and Gravel. In this case, again, the loam is in places contorted and disturbed; but, far from being Contorted Drift, it is of post-Glacial age containing a Palæolithic floor.

It has been suggested that some of the loam and Boulder Clay of the remarkable Sudbury sections is of Lower Glacial age, and equivalent to the Norfolk type. The Rev. E. Hill, after a careful study of the deposits, cannot accept this view.[3] No igneous erratics, like those that are so very characteristic of the Contorted Drift, have yet been found in it; nor is it, in my opinion, similar in appearance to the last-named deposit.

It is pretty well established, then, that the radiating valleys here dealt with (other than the border river, the Waveney) cannot cut through the Lower Boulder Clay: since, if it ever existed over Mid- and South Suffolk (of which there is no direct or indirect evidence), it must have been denuded off before the advent of the Glacial Sands and Gravels and the Upper Boulder Clay. The valleys are thus later in age than the Red, Norwich, or Chillesford Crag, according to which occurs. By analogy, however, with the Waveney and the Norfolk rivers (particularly the Wensum and the Yare), which Mr. F. W. Harmer has considered in detail,[4] the

[1] Mem. Geol. Surv. 1886 (11) pp. 28, 29, & 30.
[2] *Ibid.* p. 29.
[3] E. Hill, 1912 (34) p. 28.
[4] Harmer, 1910 (29) p. 130.

Suffolk valleys are possibly also of post-Lower Boulder Clay age, but of this there is no direct evidence. At any rate, the Lower Boulder Clay is never found extending down into the valleys, and lying in them. Where it occurs in the north, it is cut through by them.

The Waveney Valley, bordering Suffolk and Norfolk, will only be considered incidentally, as it has already been dealt with by Mr. Harmer.

III. Position of the Upper (Chalky) Boulder Clay.

As described above, the Drift deposits of the greater part of Suffolk consist of the Upper (or Great Chalky) Boulder Clay, underlain by sands and gravels with intercalated loams, classed in the Memoirs of the Geological Survey as 'Middle Glacial.' (As there are no Lower Glacial deposits over nearly the whole county, the name is hardly suitable. It is not at all certain that the beds are equivalent in age to the 'Middle Glacial' of Norfolk, where the Lower Glacial beds do occur.) In each of the main valleys, reference to the 1-inch Geological Survey maps shows that the Upper Boulder Clay transgresses the various outcrops exposed, resting promiscuously on each descending member of the Pliocene or Eocene Series, or even upon the Chalk where that bed reaches the surface. Subsequent mapping on a larger scale (6 inches to the mile) has enabled me to confirm this, the way in which the Boulder Clay wraps over from the plateau into the valleys being highly characteristic of that deposit. Sections of beds exposed in the valleys also indicate the same fact; and, in cases too numerous to mention, the Drift ploughs into and overlies the older beds. A few typical sections only in each valley need be mentioned:—

Waveney Valley.—As pointed out by Mr. F. W. Harmer, the features of this valley are similar to those of the Central Norfolk rivers. The classic sections of Beccles, for example, show Chalky-Kimeridgic Boulder Clay resting on Chillesford Beds down in the valley at about 30 feet O.D. and upon the Contorted Drift, a mile to the south, at about 70 feet O.D.

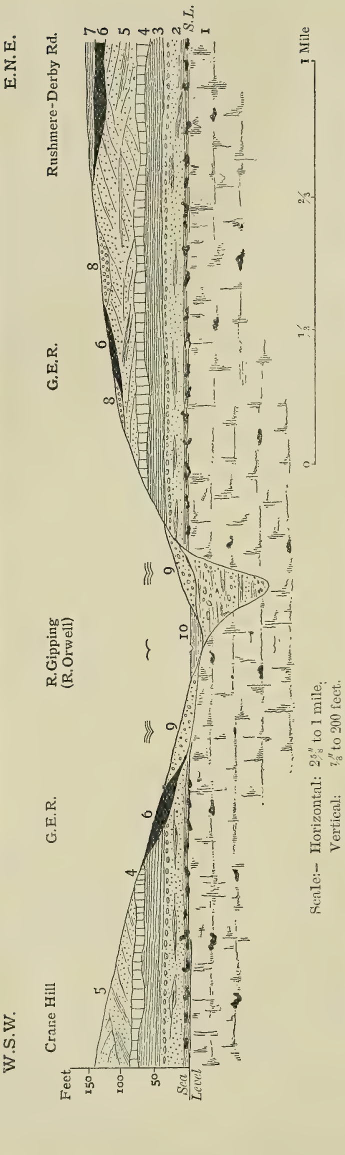
Alde Valley.—The Boulder Clay extends down into the Marlesford and Saxmundham tributary valleys, and is seen in pits at Blaxhall, on the banks of the main stream, as a valley-deposit at 50 feet O.D.

Butley Valley.—The stream occupying this is now really tributary to the Alde (=Ore) at Orford, and the famous Chillesford-Church pit, at just less than 50 feet O.D., shows the Upper Drift resting on estuarine Chillesford Clay and Sands.

Deben Valley.—Of numerous sections, that at Wickham Market may be cited, where there was a brickyard in Boulder Clay down in the valley at less than 50 feet O.D.

Gipping Valley.—This is the most typical of the Suffolk valleys, both on account of its relatively large size and on account of the sequence of strata which it exposes on its sides: that is, a

Fig. 1.—*General section across the Gipping (Orwell) Valley at Ipswich, showing the buried channel.*



[1 = Upper Chalk.
2 = Lower London Tertiaries: Thanet Sands, etc. at the base; Woolwich & Reading Beds; Oldhaven Pebble-Bed.
3 = London Clay.
4 = Red Crag.
5 = Glacial sand & gravel.
6 = Upper Boulder Clay.
7 = Loam & brickearth (post-Boulder Clay).
8 = Glacieluvial gravels.
9 = River-terrace (sand & gravel).
10 = Alluvium.]

complete series from the Chalk to the post-Glacial gravels. I have mapped a considerable portion of the valley on the scale of 6 inches to the mile; and this work, together with the very large number of excellent sections exposed in the valley, has brought out many interesting points. Almost any part of the valley might be chosen, but a section across it near Bramford[1] or Ipswich (see fig. 1) is fairly typical. Here, within a small area, pits can be examined where the Boulder Clay is seen resting on Chalk, Lower London Tertiaries, London Clay, or Glacial Sands and Gravels. The Boulder Clay forms the plateau-land of Suffolk from 100 to 400 feet O.D., but here in the valley it is found at 30 to 40 feet O.D. (Ipswich railway-cutting, Sproughton, and Bramford). The manner in which the

[1] Boswell, 1912 (33) p. 235 & map, pl. xxxiv.

Boulder Clay extends down into the small tributary valleys and sometimes thickens as it does so, being more denuded off the uplands, is brought out very strikingly in course of mapping the ground. The lateral valleys between Ipswich and Needham Market illustrate this point; and in the valley of the Belstead Brook (south of Ipswich), at Thorrington Hall Crag-pit, Boulder Clay ploughs down into the Pliocene Beds.

Brett Valley.—At Layham, Hadleigh, and other places northwards to Nedging, similar phenomena are observed. Indeed, the Brett Valley is in many ways a small edition of the Gipping Valley.

Box Valley.—At Polstead and Boxford in this small valley which runs southwards to the Stour, the Boulder Clay occurs as a valley-deposit. Excellent sections of the very chalky Boulder Clay of West Suffolk were recently exposed at the old Tudor house south-west of Boxford Church.

Stour Valley.—The classical sections of Sudbury need only be quoted. The Rev. E. Hill is 'inclined to look on them [that is, the beds of Boulder Clay] as deposited on the sides of pre-existing hollows'.[1]

The sands and gravels occurring below this Upper Boulder Clay often behave rather curiously in the valleys of South Suffolk. In many cases they certainly appear to transgress the Eocene outcrops and dip down into the valley, resting in places on the Reading Beds (Whitton) or on the Chalk (Bramford). The difficulty is that here we may be dealing with gravels of two or more different ages. The fact that the gravels often contain much Jurassic débris and many flint-casts of Chalk fossils (low-zonal forms) makes it apparent that they are outwashes from the oncoming Boulder Clay and its ice-sheet.[2] Hence they should rather be classed as Upper Glacial with the Boulder Clay, than as a separate series. The loams which occur lenticularly in them, and are formed as washes from the Boulder Clay, are then easily explicable.

This evidence from the Upper Glacial deposits goes to prove that the present broad type of valley-system was clearly pre-Upper Boulder Clay in age, and, probably in part also, older than some of the Glacial Sands and Gravels. The rivers, however, appear to cut through the rather different sands and gravels which form so large a part of the Suffolk heathland.

IV. Evidence of Age adduced from Glacial Disturbance in the Valleys.

The phenomena discussed in this section belong to the valleys of the Alde, Deben, Gipping, Brett, Box, and Stour, but are best exemplified in the Gipping Valley where more work has been done upon them. The last-named valley is comparatively large,

[1] E. Hill, 1912 (34) p. 26.
[2] Mr. Harmer has, I believe, suggested this on other grounds.

and from the nature of the beds disturbed lends itself to more detailed treatment.

Gipping Valley.—The plateau around the valley is at a level of 150 to 200 feet O.D., and to understand the relief of the district reference must be made to a coloured contour-map (Pl. LV, fig. 1). The valley proper is mainly the portion below the 100-foot contour; and it will be seen that, in places, all down the valley on both sides 'bluffs' or 'spurs' of land project inwards.[1] In most cases the bluff is indicated by the swelling of both the 50-foot and 100-foot contours, but sometimes by the former only. Over twenty definite cases of disturbance of some or all of the beds of the district (Chalk, Thanet Beds, Reading Beds, London Clay, Crag, and Glacial Beds) were recorded by the officers of the Geological Survey, some being referred to glacial action as a cause.[2] More recent work has been carried out by Mr. George Slater, exceptional opportunities having arisen in recent years for the detailed study of the remarkable glacial phenomena in this valley.[3]

When the exact positions of all these sections showing intense disturbance and buttressing are plotted on the contoured map, it is found that each is located upon one of the spurs mentioned above, and that there are no records of any considerable disturbance in any of the numerous sections exposed on the plateau. The presence of disturbance upon every important spur down the valley (as noted by the Geological Survey, Mr. Slater, or myself), and the absence of such elsewhere, precludes the possibility of mere coincidence. The position of such recorded disturbances (buttressing, contortion, shearing, transportation, etc.) is shown in each case on the map (Pl. LV, fig. 1), by an arrow marking the direction from which pressure appeared to come, as determined by the phenomena there observed. In detail, the chief places are:—

(*a*) Gallows Hill, Barking, near Needham Market.[4]—Actually there are two hills bearing the same name. The sections showing disturbed beds on the more northern of the two spurs have not yet been described in detail, although good sections are at present visible there. Those on the more southerly spur and on the sides of the railway-cutting through it are now covered with talus and grassed over, but were noted by Sir J. B. Phear[5] and by the officers of the Geological Survey.[6]

[1] Sir J. B. Phear seems to have observed some of these, and termed them 'sand-cliffs' in his 1856 paper (1) p. 434, &c.

[2] Mem. Geol. Surv. 1881 (8) & 1885 (10), pp. 9, 18, &c.

[3] Slater, 1907 (22) p. 186, & 1911 (32) p. 11.

[4] Many of these projecting spurs into the valleys have received the name 'Gallows Hill' in Suffolk, the reason being obvious. Their conspicuousness also accounts for the term 'Beacon Hill' applied to many of them. Some in the Gipping Valley are alleged to have been fortified by the Romans, and used as stations overlooking and guarding the Roman road which runs up the valley on its course to Norwich.

[5] Sir J. B. Phear, 1856 (1) p. 436.

[6] Mem. Geol. Surv. 1881 (8) p. 7.

(*b*) Opposite to Gallows Hill, on the left bank, the small tributary stream known as the Coddenham Brook joins the main river. The result of this is to produce a strong bluff (Beacon Hill) at the northern end of Shrubland Park, pointing, as it were, up the valley, on account of the angle at which the tributary valley comes in. The high road cuts through the Chalk forming this bluff, and descends a steep hill. Some 15 to 20 feet of Chalk is thus laid bare on the roadsides, and a careful examination of this has convinced me that the whole of the material exposed is much disturbed: in fact, the Chalk is shattered to a breccia or conglomerate of Chalk pebbles in a marly matrix. The top portion is much mixed and is full of flints, many large and green-coated (from the Thanet Beds), the bedding-planes of the Chalk being wavy. The surface of the latter is very irregular, and is covered by sand and gravel (pockets of which also occur in the Chalk); and above the gravel in one place buff and grey loam occurs. This shattering and loosening of the otherwise very firm Chalk accounts for the whole section being pale red in colour, owing to the percolation of ferruginous waters (not merely down the joint-planes, as is usually the case). The disturbance probably accounts for the many 'pipes' formed here by root-action. It is noteworthy that at this hill the surface of the Chalk is about 120 feet above O.D., whereas its ordinary level in pits and borings in the immediate neighbourhood is about 100 feet above O.D.

(*c*) Descending the valley, the next projection of importance that we reach is on the right bank at Baylham. The Chalk-pit east of the high road shows much disturbance of the strata, and has been figured by Mr. G. Slater.[1]

(*d*) At Claydon, on the left bank, an important bluff occurs, and luckily a large Chalk-pit is excavated in it. The remarkable section here, illustrating the work of the valley-glacier, was roughly figured and described by Mr. W. Whitaker,[2] and later carefully worked out and drawn by Mr. Slater.[3]

(*e*) The spur near Old Hall, caused by the union of the small Akenham Brook with the main stream, contains a pit in shattered Chalk, but reference will be made later to the results of mapping this area in detail.

(*f*) We meet no other striking sections until we reach the curious spur on the left bank, a short distance north-east of Sproughton Church. However, the 6-inch mapping of the right bank from Little Blakenham, through Bramford to Sproughton, brings out many anomalies, and there seems to be a probability of disturbance east and south-east of Sycamore House, and on the

[1] Slater, 1907 (22) pl. v, fig. 12.
[2] Mem. Geol. Surv. 1881 (8) p. 10.
[3] Slater, 1907 (22) pl. v, fig. 7.

hills near Bramford Park.[1] The hill above mentioned, north-east of Sproughton Church, is almost converted into an island lying in the valley by the road and railway-line which cut across its neck. Indeed, if for any reason the river-system were revived, the Gipping would certainly take the shorter course across the neck, and leave its old winding channel as an oxbow lake. (This seems to have happened with the Stour near Sudbury: see p. 596 & Pl. LV, fig. 3.) A pit on the south-east side of the spur shows Boulder Clay ploughing into Thanet Beds; but it was the mapping of the north-western border which made evident the fact that practically the whole hill was intensely disturbed.[2]

(*g*) The valley now broadens out before reaching the estuary and the sea, but an important hill between the Hadleigh and London roads at Ipswich partly bars the way (fig. 4, p. 602, extreme left). It is not often that geologists are favoured by circumstances such as the following. The Great Eastern Railway main line to Norwich and Yarmouth makes an admirable cutting straight through the hill, and the remarkable disturbance of the strata exposed at the time was noted by Wood & Harmer,[3] and by Mr. W. Whitaker,[4] in the Geological Survey Memoir. Later, the cutting was widened on the north-east side, affording a magnificent section, which was accurately worked out by Mr. Slater in 1900[5]; once again, in 1911, the cutting was widened on the south-west side, and so provided another excellent section. In the latter part of 1912 the north-eastern embankment was again cut back. These recent sections will shortly be figured and described by Mr. Slater. Further, in 1905, the municipal authorities of Ipswich, wishing to provide work for the unemployed, decided to cut away and level this hill to a considerable extent, with the view of providing suitable building-sites. The work continued until 1910, almost 200 men at times being employed. Full advantage was taken of these excavations, which were carried out generally in a north-east and south-west direction. The sections were carefully drawn and photographed before they passed out of existence, and their value lies largely in the fact that, with the railway-cutting, they give a faithful picture of the disturbance along the line in which the ice moved and transversely to it.[6] The cutting of trenches for sewers, etc. over this estate has recently revealed still more evidence of disturbance.

(*h*) Another hill occurs immediately south-east of Ipswich Railway-Station. Some considerable disturbance is seen in cuttings here, and the strata met with during the making of the

[1] Boswell, 1912 (33) pl. xxxiv.
[2] *Ibid.* pl. xxxiv.
[3] Wood & Harmer, Rep. Brit. Assoc. 1868 (3) Trans. Sect. p. 80. See quotation on p. 584 of this paper.
[4] Mem. Geol. Surv. 1885 (10) pp. 10, 93, etc.
[5] Slater, 1907 (22) pl. v, fig. 1.
[6] *Ibid.* pl. v, figs. 2, 3, 4, 5, & 6.

Ipswich Tunnel appear to have been anomalous in position. Irregularity was noted by the officers of the Geological Survey here, and at the old Stoke brickyard (which has now disappeared), close by on the south.[1]

(*i*) Across the valley, on the left bank, there are two spurs projecting southwards into the lower ground, near Dale Hall, north-north-west of the town. Excavations in Messrs. Bolton & Laughlin's brickyard in the more northerly spur have developed a fine example of glacial disturbance, described and figured, with photographs, by Mr. Slater.[2] There are several pits showing much disturbance (sheared and puckered London Clay, etc.) in the southernmost of the two spurs—that of Broom Hill.

(*j*) At the eastern end of the town of Ipswich, disturbance was noted and figured by Mr. W. Whitaker in the railway-cutting south of the cemetery[3]; but no good sections have been visible for some time.

(*k*) In a road-cutting and other excavations in the next hill on the south (that of Grove Lane, Ipswich), Mr. Slater described and figured contortion and ploughing-up of the beds.[4] Red, highly ferruginous, glacieluvial gravels occur here.

No sections are exposed in the last spur immediately south of Greenwich Farm, neither has this yet been mapped on a larger scale.

From these observations it is clear that the Gipping Valley is considerably older than the advent of the valley-glacier, and not only the main valley, but also the two or three chief tributary valleys, as shown by the buttressing of the ice upon the spurs formed on the southernmost side at their union with the main valley. The final test of this deduction lay in mapping two of the spurs where no section had been exposed. Like the attempt to map the Hadleigh-Road hill, west of Ipswich, it was found somewhat difficult to do this satisfactorily. The first spur chosen was that north-east of Sproughton, and the result was that Glacial deposits, Eocene beds, and Chalk were found to be much mixed, and all at abnormal levels (see Hazel Wood on the 6-inch map).[5] The second case was that of the hill near Old Hall, west of Akenham, 4 miles north-west of Ipswich, where similar results were obtained. There is also a chalk-pit here, where the beds appear to be much shattered.[6] The Glacial Drift is so irregular, and members of the series pass so frequently one into the other, that the attempt to draw hard-and-fast boundary-lines on a map often results only in introducing artificialities. The most exact

1 Mem. Geol. Surv. 1885 (10) pp. 11 & 93.
2 Slater, 1911 (32) p. 13 & pl. vii.
3 Mem. Geol. Surv. 1885 (10) p. 89 & fig. 25.
4 Slater, 1907 (22) pl. v, figs. 9, 10, & 11.
5 Boswell, 1912 (33) pl. xxxiv.
6 *Ibid.* pl. xxxiv.

mapping can be at best an approximation. It seems more than probable that if other hills on the flanks of the valley were excavated, as those farther south have been, just as remarkable a series of phenomena would be exhibited.

The length of the portion of the valley that has been dealt with in detail above is some 14 miles.

It is not possible, nor is it necessary, to discuss the other Suffolk valleys in such detail. The number of sections exposed on spurs in the other smaller valleys is naturally less, but enough will be summarized for the purpose of showing that the same conditions obtained.

Alde Valley:—(*a*) There is a spur on the right bank a mile and a half south of Framlingham, through which runs a railway-cutting showing contorted beds.[1] The officers of the Geological Survey here noted

'sand, with a little gravel. At a point about 130 yards west of the 89th mile-post, is earthy gravel with a seam of clay showing strong contortions and even inversion.'

(*b*) Upon the spur on the left bank, a mile south of Framlingham, contortion and abutting of the Boulder Clay against other beds was noted.[2] A detailed description is given in the Geological Survey Memoir, and the irregularity of the beds, as observed in mapping, remarked upon.

(*c*) The spur on the left bank at Parham Wood shows some disturbance, again first noted by the officers of the Geological Survey.[3] A steep-sided channel eroded in Crag sand was observed in the railway-cutting.

(*d*) In the spur south of Snape Church, several pits, including a brickyard, show much confusion of the beds. These were observed by both S. V. Wood, Jun., and the Geological Surveyors.[4]

(*e*) Spurs at Blaxhall, on the right bank of the river, contain two pits, which I have figured, disturbances being described and, in one case, figured by the officers of the Geological Survey.

(*f*) The rise upon which Aldeburgh itself stands evidently proved an obstacle to the ice: for, in the brickyard, intense contortion of Chillesford Clay and Crag, etc., was to be seen some years ago. The course which the River Alde now takes for 10 miles southwards before entering the sea is post-Glacial deflection due to southerly tidal drift.

Other smaller disturbances also occur in this valley.

Deben Valley.—Comparatively few sections are exposed in this smaller valley, but there is evidence of disturbance.

(*a*) At the spur at Naunton Hall, Rendlesham, on the left bank.[5] Here, in the Stackyard Pit, a mass of Boulder Clay with almost, if

[1] Mem. Geol. Surv. 1886 (11) p. 33.
[2] *Ibid.* pp. 33, 34. [3] *Ibid.* p. 34.
[4] *Ibid.* p. 29. [5] *Ibid.* p. 40.

not absolutely, vertical sides occupied a deep gully in the Crag, the trend of which was north-north-westerly, pointing up the upper part of the valley, but almost at right angles to the course of the Deben at this place.

(*b*) The disturbance at Hasketon brickyard should be mentioned here. It may be connected with the valley-ice, but is local in character.

(*c*) The anomalous levels of the Reading Beds, London Clay, and Crag at Woodbridge, and the sequences of strata met with in well-borings, point to much disturbance (see p. 607).

Brett Valley (Pl. LV, fig. 2).—This is a miniature of the Gipping Valley, showing similar phenomena on a smaller scale.

(*a*) From the irregularity of the beds, there seems to be disturbance at the spur on the right bank, south of Semer Church, and also farther south near Cosford Union Workhouse.

(*b*) At the big spur north-west of Hadleigh, on the right bank, considerable disturbance of Eocene beds was figured by Mr. W. Whitaker,[1] and, later, different sections were figured by myself.

(*c*) The hill on which Hadleigh Railway-Station is situated, on the left bank, is capped by disturbed Glacial beds, but no good sections lower down the hill are visible.

(*d*) In the Geological Survey Memoir disturbance is noted and figured at several places on the right bank: for instance, near Overbury Hall, Layham.[2] The spur south of Layham Church contains a brickyard where fine contortions in loam, sand, and Boulder Clay were to be seen.

(*e*) There is good evidence of disturbance near Shelley Church, Eocene beds, etc., occurring at very unusual levels.[3]

Stour Valley (Pl. LV, fig. 3).—As would be expected from the position, disturbed beds were noted at the brickyard at Boxford, where the valley and stream change direction from east to south, the River Box being tributary to the Stour. The brickyard is now disused, and the sections are overgrown; but contorted London Clay, Glacial Sand, and Boulder Clay (the last extending down into the valley) were observed and figured in 1885.[4]

The Stour, cutting, as it does, its valley largely through Chalk, is not quite comparable with other Suffolk rivers. The disturbance also seems to be of a type rather different from that observed farther east, being characterized by an accompaniment of large quantities of chalky sands and bedded chalky silts or loams. These are not strictly paralleled by anything in the east of the county, although similar sands and silts do occur in very

[1] Mem. Geol. Surv. 1885 (10) p. 21 & fig. 7.
[2] *Ibid.* pp. 88, 100, etc.
[3] *Ibid.* pp. 9–10.
[4] *Ibid.* pp. 18–19 & fig. 5.

small quantity, as, for example, at Barking and Stowmarket, etc. The occurrence of this large quantity of chalky material is clearly due to the higher level of the Chalk surface hereabouts, its relatively greater area of outcrop, and thinner overburden of Eocene and Crag deposits. It seems probable that the absence of any notable thickness of London Clay has in no small degree modified the nature of the disturbances. Some contortion and minor faulting of the silts at higher levels is doubtless due to slipping on the valley-slopes, as explained by the Rev. E. Hill in his clear and accurate description of the Sudbury Glacial sections[1]; but it seems to me quite probable that some of the disturbance on the Sudbury Town spur, and on the Ballingdon Grove spur on the opposite bank, may be due to buttressing upon them. Contortion, inversion, and buttressing of the beds are to be seen, and mapping on a large scale might throw light on the matter.

In the brickfield situated on the spurs a mile west-south-west of Little Cornard Church, occur good exposures of bedded silts and chalky sands completely enclosing huge boulders of altered or redeposited Chalk. Their appearance at once recalls the Cromer and Norfolk coast Chalk-masses, as was observed by Mr. Hill,[2] who points out the narrowing of the valley here, and suggests that the great boulders of remanié Chalk were stranded in their present position. I am compelled to agree entirely with this view, and it is interesting to draw attention to the form of the valley immediately above these spurs projecting from the plateau (Pl. LV, fig. 3). The 100-foot contour is here thrown back into a bay-like form, and a tract of absolutely flat country a mile long and nearly as broad occurs. In this embayment the slope from the 100- and 200-foot contours to the river is not gradual, but is the normal gradient of the valley-flanks near by, reaching river-level immediately west of the 100-foot contour. This comparatively extensive flat plain is in many parts liable to floods, and is traversed by ditches and small streams which drain it. It is largely covered by alluvium, but loam and gravel were also mapped. There seems little doubt that here the Stour in pre-Glacial or early Glacial times made a big bend similar to those in the upper part of its course; but eventually (perhaps in consequence of increased volume due to the melting of the Upper Boulder-Clay ice), it cut off this bend, and took its present direct course, producing a flat river-formed plain and an oxbow channel which has been silted up. The meniscus-shaped outcrops of loam and valley-gravel mapped by the officers of the Geological Survey bear out this view. (Compare the Sproughton spur in the Gipping Valley, p. 592.)

In the investigation of these disturbances due to glacial action (many of them on a considerable scale), every example of contortion and displacement recorded or observed in the county is found

[1] E. Hill, 1912 (34) p. 27.
[2] *Ibid.* p. 28.

to lie on the flanks of the valleys. Nowhere in the numerous sections on the plateau have such anomalies been observed (although one or two hypothetical sections have been drawn on quite insufficient evidence), neither do the well-records there show anything but a normal state of affairs. The fact that marked disturbance occurs only in the valleys, seems, therefore, to be more than mere coincidence. It is probable that the ice-sheet which produced the Chalky and Chalky-Kimeridgic Boulder Clay of the plateau rolled upon a bed of Glacial Sand and Gravel, producing the generally flattened character of the latter deposits.

The conclusion drawn, therefore, from a study of the spurs of the Suffolk valleys is that the pre-Glacial or early Glacial contours of the area were, in the main, much as they are at the present time.

V. Evidence of Age from Well-Borings, etc.

The records of the strata shown by over 600 borings in Suffolk and on the borders of Essex and Norfolk have been analysed. Many of these, for various reasons (not the least of which is the lack of information as to altitude and exact situation of the boring), were of little or no use, but over 200 were accurately plotted on a map of Suffolk (Pl. LIV). The sites of most of these borings, especially the critical ones, have been visited, and in many cases the exact site and the height above Ordnance Datum have been obtained where they were previously missing in the records. The production of a sub-Drift contoured map was at first attempted, but was abandoned on account of the necessarily arbitrary grouping of the strata in the well-borings, etc., where Glacial beds of sand, loam, and clay were resting on Crag sand (=decalcified Crag) and Eocene clays and sands.[1] No geologist having been present when most of the borings were made, it appears that the only bed the level of which can be widely relied upon is the Chalk. On the map (Pl. LIV) the approximate contour-lines for the Chalk surface on the plateau are inserted, in order to bring out the anomalous levels in the valleys where buried channels occur. The noteworthy 'crowding-up' of the contours in the south and east of the county is explained when the present extent of the Eocene deposits is marked upon the map. The gradient of the Chalk surface where it crops out, or is covered only by Drift, is closely 7 feet to the mile; but, where covered by Eocene deposits, it dips almost 30 feet to the mile.[2] The unconformity of the Eocene upon the Cretaceous is well brought out, when it is noted that the dip of the Chalk zones is about 15 feet to the mile. This unconformity is further

[1] In a recent letter Mr. F. W. Harmer tells me that some years ago he spent much time in trying to work out the sub-Glacial contours of Norfolk by the same method, but without success.

[2] Boswell, 1913 (37) p. 18.

emphasized in the south of the county by the transgression of the Tertiary strata westwards over successively lower zones of the Chalk.

Naturally, the larger valleys cut back these Chalk-surface contours, and these take either a sharp V-form, or a closed oval form where a channel exists; but the small scale of the map prevents me from showing these anomalies, only the chief borings in each valley being inserted. The figures, in all cases, refer to the position of the top of the Chalk with reference to Ordnance Datum, the negative sign referring to depths below O.D. In the western part of the county the Drift rests directly on the Chalk; but in the eastern portion the borings show Eocene and Pliocene strata between. As, however, it is often difficult to fix the exact base of the Drift in the well-section when it overlies Crag and Eocene deposits, the upper surface of the Chalk has been recorded in each case; it can be placed with certainty, and serves the required purpose equally well. The data are, nevertheless, insufficient to yield an accurate hypsometrical map. In this way some striking facts are brought to light. The existence of buried channels of the Drift at Glemsford,[1] Brettenham,[2] Ipswich,[3] and possibly Woodbridge[4] has previously been pointed out. Similar ones have been described on the west of the area at Hitchin[5]; in the Cam Valley in North-West Essex[6]; at Bishop's Stortford[7]; and at Sandy in Bedfordshire.[8] Examination of the well-records shows that each one of these radiating Suffolk valleys of any size contains a buried channel. The evidence for these channels will now be considered in detail.

(*a*) Stour Valley.—The remarkable thickness of Drift met with in the boring at Glemsford, north of Sudbury, has been frequently commented upon. The boring was begun at 123 feet O.D., and, after passing through 471 feet of Drift, reached the Chalk. It is not necessary to reprint full details, but the chief groupings were:—Gravel and sand 51 feet, Boulder Clay 218 feet, sand and gravel with flints 201 feet, Chalk 40 feet. This section makes the level of the Chalk −348 feet O.D., while at neighbouring places it crops out at a level considerably above O.D. (for instance: Clare +151 feet, Sudbury +110 to 120 feet). Moreover, as Mr. Whitaker points out, the section begins at some depth below the great mass of Boulder Clay, which on the plateau near by reaches a height of more than 250 feet O.D.

(*b*) Brett Valley.—At Felsham, near the head of the valley, the Chalk surface occurs at 120 feet O.D., but at Brettenham and

[1] Whitaker, 1906 (21) p. 58. [2] *Ibid.* p. 32. [3] *Ibid.* p. 77, etc.
[4] Whitaker, 1903 (20) pp. 36 & 47.
[5] W. Hill, 1908 (23) p. 8, & 1912 (35) p. 217.
[6] Whitaker, 1890 (13) p. 333. [7] Irving, 1897 (16) p. 224.
[8] J. Hopkinson, Q. J. G. S. vol. lix (1903) p. 49 (discussion).

Hitcham in the valley, as the Rev. E. Hill has pointed out in the course of correspondence, there seems to be good evidence of deep hollows in the Chalk. In the Brettenham well (280 feet O.D.) 312 feet of clays and sands were met with above the Chalk, the upper surface of which here is thus −32 feet O.D. Mr. Whitaker classes all these beds as Drift, but Mr. Hill suspends judgment. From the mixed nature of the beds in the section, one would feel inclined to suggest that Eocene and Pliocene deposits had been ploughed up and incorporated with the Drift.

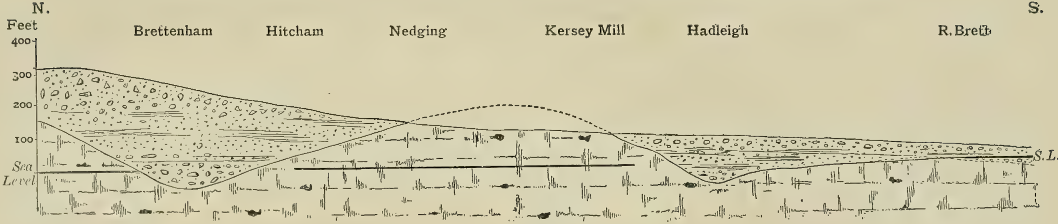
The following is the section under discussion:—

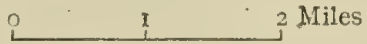
		Thickness in feet.	*Depth in feet.*
GLACIAL DRIFT.	Blue Boulder Clay with Chalk stones	141	141
	Rough red sand	16	157
	Loamy sand with grey clay	5	162
	Fine red running sand	30	192
	Grey clay mixed with red sand	6	198
	Rough red sand with shells	15	213
	Hard rocky substance	4	217
	Conglomerates	5	222
	Plastic clay with flints (? Boulder Clay)	90	312
CHALK, with occasional beds of flint		232	544

Certainly plastic clay is found in the Lower Eocene beds, but never more than a few feet thick. It should also be pointed out that Brettenham Park is about 4 miles north of the present limit of the Lower London Tertiaries; they are present at Sudbury, Hadleigh, and Ipswich, but are rapidly thinning off by erosion. Detailed mapping of the beds has proved that, even after they have disappeared north-westwards, material from them is included in Glacial Drift north of their outcrop. Their previous farther extension north-westwards is thus indicated; they and the Crag which lies above them were considerably eroded in pre-Glacial and Glacial times.

A boring in Hitcham Street (at 175 feet O.D.) went through 104 feet of Drift without reaching Chalk, which normally crops out in the vicinity at over 120 feet O.D. The Rev. E. Hill remarks that this 'is interesting as revealing a buried valley.' At Cross Green, just to the north-east, 250 feet of Drift were cut through before Chalk was reached. As we descend the Brett Valley, the Chalk is seen to crop out at the surface at 120 to 130 feet O.D. at Monk's Eleigh (zone of *Marsupites*), Chelsworth, Bildeston, Nedging (zone of *Actinocamax quadratus*); and at Cosford Bridge and Kersey, 2 miles north of Hadleigh, at about 100 feet O.D: it is also found in borings at Whatfield at over 130 feet O.D. At Hadleigh, however, a second buried channel appears to be revealed. A boring made for Messrs. Woods & Co., at 90 feet O.D., shows 90 feet of Drift lying directly upon Chalk, no Crag or Eocene deposits being recorded. A second boring at the Maltings (80 feet O.D.) cuts through a series of sands and clays 100 feet thick, which Mr. Whitaker

Fig. 2.—*Longitudinal section down the Brett Valley, showing hollows filled with Drift.*



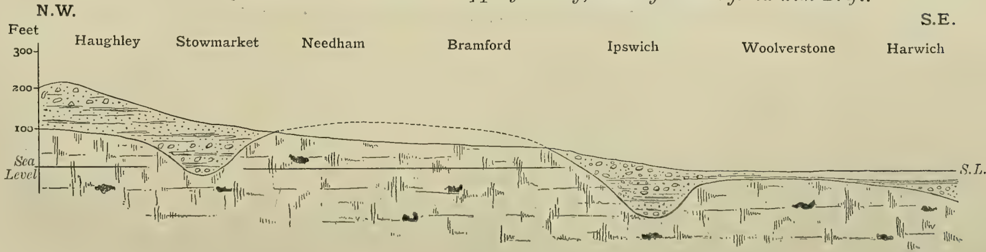


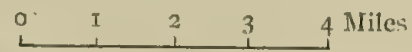
Scale:— Horizontal: $\frac{7}{16}''$ to 1 mile.
Vertical: $\frac{7}{8}''$ to 400 feet.

In figs. 2 & 3 conventional shading is employed to represent the Boulder Clay, Loam, Sand, and Gravel, which fill the hollows in the Chalk.

[The dotted lines indicate the level of the Chalk surface on the sides of the valleys. In fig. 2 this is drawn a little too high: it should reach to about 140 feet O.D.]

Fig. 3.—*Longitudinal section down the Gipping Valley, showing hollows filled with Drift.*





Scale:— Horizontal: 4 miles to 1 inch.
Vertical: 400 feet to 1 inch.

classes doubtfully as '? all Reading Beds.' Neither the thickness nor the levels support this possibility; the beds seem to be very much mixed, and are probably reassorted material in Drift. The top of the Chalk is thus below O.D. A general consideration of all the borings in the county and the drawing of approximate contour-lines would lead to the conclusion that, even allowing for local dips, Chalk should crop out in this valley with its surface at about +80 feet O.D. at Hadleigh. Recent borings at Hadleigh, near the river-level, show 72 and 79 feet of Drift. The subjoined table gives details of the borings in the Brett Valley and establishes the presence of one or more buried channels (see fig. 2, p. 600).

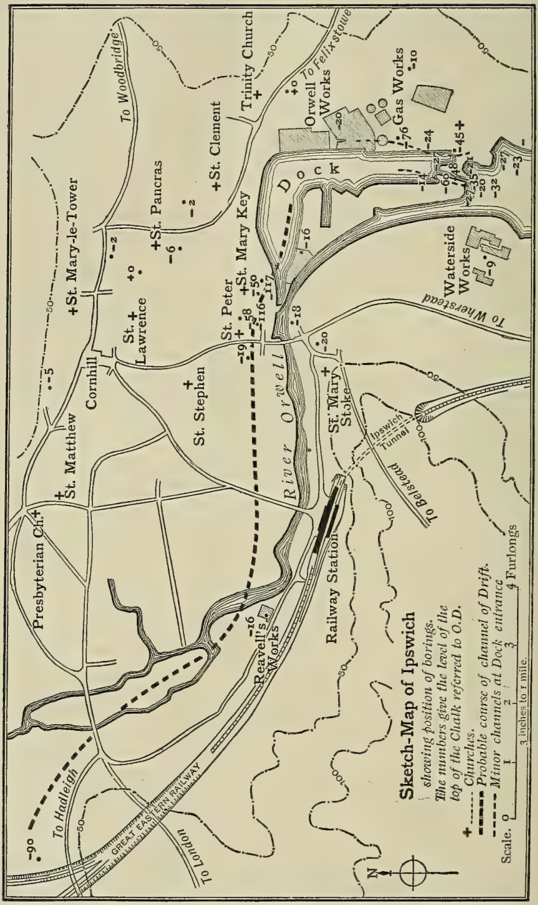
TABLE OF BORINGS IN THE BRETT VALLEY.

Position.	*Height above O.D. in feet.*	*Thickness of Drift in feet.*	*Chalk-surface referred to O.D. in feet.*
Felsham	270	150	+120
Brettenham Park	289	312	− 32
Hitcham	175	104+	below +70
Cross Green	300	250	+ 50
Bildeston	118	—	+118
Chelsworth and Monk's Eleigh	120–130	—	+120
Whatfield	200	60	+140
Semer	100	20	+ 80
Kersey	90–100	—	+ 90
Cosford	126	95½	+ 31½
Hadleigh—Woods & Co.	90	90	+ 0
Do. Wilson's Malting	80	100	− 20
Do. by the river	60	102	− 42
Do. 1909, Deanery	70	72	− 2
Do. 1911	80	80	+ 0

(*c*) Gipping Valley.—The existence of a similar channel in the Gipping Valley, just at the head of the Orwell Estuary, was noted as far back as 1885,[1] in the boring at St. Peter's Quay. Subsequent borings have confirmed this earlier record. The chief of twenty wells and over seventy trial-borings are shown upon the sketch-map (fig. 4, p. 602), and it is probable that if a town of the size of Ipswich had been situated in any of the other valleys of Suffolk, we should have had just as much more definite information as to the extent of the channel in that valley. Beginning at the upper end of the valley, in the neighbourhood of Stowmarket, there seems to be good evidence for a channel. The Chalk by protraction should here be reached at about 120 feet O.D. It crops out 2 miles

[1] Mem. Geol. Surv. 1885 (10) p. 118.

Fig. 4.


Sketch-Map of Ipswich
showing position of borings.
The numbers give the level of the top of the Chalk referred to O.D.
Churches.
Probable course of channel of Drift.
Minor channels at Dock entrance
Scale. 0 1 2 3 4 Furlongs
3 inches to 1 mile.
Presbyterian Ch.
St. Matthew
St. Mary-le-Tower
Cornhill
St. Lawrence
St. Stephen
St. Pancras
St. Clement
Trinity Church
St. Peter
St. Mary Key
St. Mary Stoke
River Orwell
Dock
Orwell Works
Gas Works
Waterside Works
Reavell's Works
Railway Station
Ipswich Tunnel
GREAT EASTERN RAILWAY
To London
To Hadleigh
To Woodbridge
To Felixstowe
To Wherstead
To Belstead
N

to the south-east at 100 feet O.D., but the following table shows the actual levels found :—

Table of Borings in the Gipping Valley—Upper Portion.

Locality.	*Height above O.D. in feet.*	*Thickness of Drift in feet.*	*Chalk-surface referred to O.D. in feet.*
Elmswell	217	127	+ 90
Old Newton	210	128	+ 82
Haughley	160	100	+ 60
Stowmarket—Malting	92	57½	+ 34½
Do. Brewery	100	71	+ 29
Do. Brickyard	135	113	+ 22
Do. Waterworks	100	77½	+ 22½
Do. Hewitt's Mill	95	100	− 5
Creeting St. Peter	164	145	+ 19
Combs	100	? 57	? + 43[1]
Needham Market	100	—	+100
Chalk-pit near Creeting Hall	100	—	+100

Other wells show a corresponding thickness in Drift, but that at Creeting St. Peter is a little surprising, as it lies rather outside the present valley, while Chalk is exposed at a higher level at a pit in the valley (Creeting Hall). The surface of the Chalk is very irregular here, but a little lower down the valley the formation crops out again at the levels to be expected, 100 to 120 feet O.D. (Baylham, Bramford, Claydon, Needham, etc.).

A number of fresh borings have recently been put down at Ipswich, and these give more definite information as to the extent of the buried channel there. Fig. 4 (p. 602) is a map of Ipswich upon which these borings have been inserted. In the area round the Dock some forty trial-borings, etc., had already been recorded; in 1912–13 over thirty more have been made in connexion with the proposed Dock-extension. Space permits only of the chief of these being inserted. At present, only an average example of the new borings need be quoted :—

	Feet.
Alluvium. River-mud	2
Terrace. River-gravel	7
Chalk	10+

Many of the borings are begun beneath low-water, which is, for spring-tides, −4 to −6 feet O.D., high-water being +9 feet O.D.[2] The level of the Chalk thus indicated varies from −25 to −32

[1] Two accounts of this well do not agree; see Whitaker, 1906 (21) p. 39.

[2] For this information, and that relating to the new Dock-borings, I have to express my thanks to Mr. Thomas Miller, C.E., Engineer to the Ipswich Dock Commissioners, and his son, who have very kindly given me every assistance.

feet O.D. Along the broken lines on the map, near the Dock-entrance, there seem to be hollows in the Chalk: that on the west being indicated by the old series of borings, that on the east being indicated by the new. However, the hollows do not appear to be of any great extent or importance, though they may be the end of the proved deep channel. The well-boring for the Gas-Works in Patteson Road (1905) yields evidence of a Drift-filled hollow, but whether it is connected with the deep channel, or with the minor channels at the Dock-entrance, we do not know. The particulars of the boring are:—

Ground-level +14 feet O.D.

		Thickness in feet	inches.	Depth in feet	inches.
ALLUVIUM and TERRACE.	Made soil	5	6	5	6
	Coarse ballast	3	0	8	6
	Black mud	3	0	11	6
	Coarse dark ballast	11	6	23	0
DRIFT.	Light loam	4	6	27	6
	Running sand	8	0	35	6
	Dark loam	6	0	41	6
	London Clay [1]	2	0	43	6
	Loam sand	6	6	50	0
	London Clay [1]	5	9	55	9
	Loam and sand	9	6	65	3
	Light-brown clay	0	9	66	0
	Flint-bed and gravel	18	0	84	0
	Light coarse sand	2	0	86	0
	Sandstone	1	0	87	0
	Flint-bed	3	0	90	0
CHALK		160	0	250	0

Surface of Chalk −76 feet O.D.

If the hollows indicated by the Dock-borings and this Gas-Works boring are connected with the proved deep channel, the result would be interesting, as their direction is at right angles to that of the proved channel, and it would indicate that the hollow changed direction sharply with the present estuary. Until recently there were two anomalous borings reaching Chalk at considerable depths only. The details of the strata bored through have been frequently reprinted,[2] and it is unnecessary to give more than a summary here:—

(1) *College Street, Messrs. Burton & Saunders.* *(14 feet O.D.)*

	Feet.
Drift	130
Chalk	191½
Chalk-level	−116 O.D.

(2) *St. Peter's Quay, Messrs. Cranfield.* *(10 feet O.D.)*

	Feet.
Drift	127
Chalk	81
Chalk-level	−117 O.D.

[1] The well-sinkers' term only. The grouping of the beds is mine.
[2] Mem. Geol. Surv. 1906 (21) p. 74, etc.

Other borings put down in Ipswich and the neighbourhood since the last list, published in 1906,[1] prove the Chalk to lie at the customary levels; but a boring begun in December 1912, and finished early this year (1913), immediately west of the town, proves the extension of the buried channel farther westwards. I was able to see the early part only of the boring, and I have to express my gratitude to my friend, Mr. Slater, who, being on the spot, carefully made detailed notes and kept samples of all the beds met with. I have used his notes freely in the following:—

Ipswich.—Boring for water for the Diesel Engine-Works by the river immediately west of the town. (Height above O.D.=23 feet.)

		Thickness in feet.	*Depth in feet.*
River-Terrace.	Reddish sand	4	4
	Ferruginous flinty gravel and sand	25	29
Drift.	Silty clay	21	50
	Sharp, dark-grey sand, with specks of chalk	8	58
	Do., but finer	$7\frac{1}{2}$	$65\frac{1}{2}$
	Similar sand, but with potato-sized boulders of chalk and flints	$9\frac{1}{2}$	75
	Coarser grey sands	17	92
	Chalky flint-gravel; some quartz boulders	5	97
	Chalk (remanié material)	3	100
	Coarse gravel	4	104
	Chalk (as before)	6	110
	Very coarse gravel	3	113
Chalk		112	225

The first 29 feet is typical terrace-material, with iron-stained and much-altered flint, of a prevalent reddish or brownish tint. The grey sands and silts from 50 to $65\frac{1}{2}$ feet are, from the samples, obviously washes from the Chalky-Kimeridgic Boulder Clay: hence their colour. The uppermost 8 feet of this is a micaceous sandy loam. Two boulders of Chalk were passed through (from 97 to 100 feet and 104 to 110), consisting of rubbly altered material like the transported boulders at Little Cornard (see p. 596). Mr. Slater has recorded a huge transported boulder of Chalk, 42 feet long, higher up the valley at Claydon.[2] The 4 feet of gravel between the two Chalk masses is rather peculiar. It consists of a great deal of flint, much of it in the form of fine chippings, in a matrix of chalky sand. This flint is brown and black in colour and very fresh, even the thin translucent edges being unaltered, though perhaps a little rounded. All the flint in the Drift portion below the terrace-material is fresh and unaltered, just as it came from the Chalk. Vein-quartz pebbles frequently accompany it; but it is the last 3 feet of gravel, resting directly on the Chalk, that is the most interesting and important part of the section. This gravel consists of fresh dark-brown and black flint-pebbles, about 3 inches in diameter, many of them beautifully rounded, but still showing over parts of them the original white

[1] *Op. cit.* [2] Slater, 1907 (22) pl. v, fig. 7.

cortex. Others are subangular, in the process of being rounded off, their edges smooth, but their substance still unaltered. Mr. Slater also secured one well-rounded pebble of Jurassic limestone. The appearance of these rocks, from their shape and lack of alteration, at once suggests pot-hole action; but pot-hole action where Eocene and Crag detritus had no entry, for there is an entire absence of iron-staining. Very different are the terrace-gravels, also the glacieluvial gravels, with their intensely iron-stained and battered flints, and the 'Cannon-Shot' Gravels, with their ferruginous flints often beautifully rounded, as our specimens are.

It is possible that the flint-gravels so frequently noted at the base of other buried channels may be similar, but the well-sinkers would probably not record the difference in character of the pebbles. In normal sections in the district a band of glauconitic green-coated flints, of the usual irregular shape, generally occurs at the base of the Thanet Beds, lying directly upon the Chalk.

TABLE OF BORINGS IN THE GIPPING VALLEY—LOWER PORTION.

Locality	*Height above O.D. in feet.*	*Thickness of Drift in feet.*	*Chalk-surface referred to O.D. in feet.*
Bramford Chalk-pits	100+	—	+100
Sproughton Clay-pit	—	—	+ 50
Ipswich—Henley Road	150+	136 [1]	+ 14
Do. Tollemache's	35	35	+ 0
Do. Cliff Brewery	34	34	+ 0
Do. Co-operat. Society, Carr St.	40	42	− 2
Do. Stay Factory	47	52	− 5
Do. Unicorn Brewery	26	32	− 6
Do. Burton's Jam Factory	16	35	− 19
Do. Mason's Paper Mills	13	29	− 16
Do. Reavell's Works	18	34	− 16
Do. Gas Company, Holywells	27	37	− 10
Do. Orwell Works	12	32	− 20
Do. Near Cliff Brewery	0	18	− 18
Do. Fison's Works	12	30	− 18
Do. Waterworks	25	27	− 2
Do. Stoke Union	40	60	− 20
Do. Waterside Works	15	20 & 26	−5 & −9
Do. South of Key Church	11	61	− 50
Do. St. Peter's Works	12	70	− 58
Do. Cranfield's	10	127	−117
Do. College Street	14	130	−116
Do. Gas Company, Patteson Rd.	14	90	− 76
Do. Diesel Works	23	113	− 90
Do. Smart's Wharf	13	$40\frac{1}{2}$	− $27\frac{1}{2}$
Do. Old Dock borings	Many below O.D.	—	−13 to −60
Do. New Dock borings, average	do.	—	−25 to −32
Rushmere	82	114 [1]	− 32
Woolverstone	95	105 [1]	− 10
Butterman's Bay	—	—	Below −40

[1] Includes Eocene beds and Crag also.

(*d*) Deben Valley.—The borings in this valley near Woodbridge are more difficult of explanation. Of about fourteen well-sections recorded, ten are conformable with regard to the position of the top of the Chalk and Eocene beds, but one is anomalous. The explanation of this singular section was discussed by Mr. Whitaker and others,[1] opinions being divided; suggested causes were a Glacial channel, a huge Chalk solution-pipe, landslipping, and trough-faulting. None were satisfactory, but the last seemed to be the best. The following is the boring as recorded,[2] the square brackets indicating the proposed grouping of the strata:—

Trial boring for Woodbridge Waterworks Co., 1901.
(Height above sea-level = 18 feet.)

		Thickness in feet	Thickness in inches	Depth in feet	Depth in inches
Soil		2	0	2	0
[Drift ?]	Sand	4	6	6	6
	Gravel and flints	3	0	9	6
	Loamy sand (sandy loam)	4	0	13	6
	Sand	2	6	16	0
	Gravel	3	5	19	5
	Sand and shingle (loamy gravel)	4	0	23	5
	Mottled sand (somewhat loamy)	6	0	29	5
	Sand and shingle (fine gravelly sand)	8	0	37	5
[Crag ? 95½ feet.]	Grey sand (dark-brown silty sand)	1	0	38	5
	Fine sand (shelly sand)	7	0	45	5
	Fine sand, shingle, and Crag (gravelly sand)	60	7	106	0
	Black mud (fine gravelly loam)	1	6	107	6
	Crag with shells (shelly sand, *Turritella*)	25	3	132	9
[London Clay? nearly 20 feet.]	Claystone (septaria)	0	9	133	6
	Blue clay (stiff grey clay)	15	4	148	10
	Sand and pebbles	3	9	152	7
[Reading Beds? nearly 41 feet.]	Dark sand (grey firm sand, slightly loamy)	6	5	159	0
	Yellow sand and clay (brown sand)	15	9	174	9
	Blue clay (grey)	2	3	177	0
	Fine yellow sand (brown)	16	6	193	6
Chalk (and flints)		55	6	249	0

The Chalk was thus reached at −175 feet O.D., while its surface in wells close by occurs at from −20 to −47 feet O.D. There is no evidence of faulting or similar disturbance of the beds anywhere in the surrounding area (faults are very rare in Suffolk, and when they occur are of trivial character), and in view of glacial disturbances on a large scale seen in Suffolk valleys, it seems more satisfactory to regard the case as one of a buried glacial channel similar to those in the neighbouring valleys. It is noteworthy that a

[1] Whitaker, 1903 (20) p. 36.
[2] 'Water-Supply of Suffolk' Mem. Geol. Surv. 1906, p. 128.

channel of Drift was recorded by the Geological Survey higher up the valley at Naunton Hall.[1] The portion labelled 'Crag' may be made up of included Crag in the Drift, such as is often met with in South-Eastern Suffolk,[2] but it was the Eocene beds that were the chief argument against the 'channel' explanation. These (if they are all Eocene, which is doubtful) appear to be *in situ*; but it is quite possible that they are not (large masses of disturbed and transported Crag, London Clay, and Chalk have been recorded in the Gipping Valley by Mr. Slater, in some cases preserving their natural sequence).[3] That all this material may be mixed is somewhat confirmed by the anomalous sequence of beds found in the most recent boring at Woodbridge Waterworks (No. 1 below), although it is possible that the beds have been wrongly named. It is probable too, that Mr. Whitaker's suggestion of slips into the channel (which need not then have been at 'a goodly depth below sea-level') may be correct, especially if the channel had been eroded by sub-glacial water-streams. In any case, it appears to me that the explanation of the phenomena by means of a buried channel is quite as justifiable as the assumption of a trough-fault; and, moreover, such interpretation of the evidence brings this valley into accordance with the others.

TABLE OF BORINGS IN THE DEBEN VALLEY.

Locality.	*Height above O.D. in feet.*	*Thickness of Drift in feet.*	*Chalk-surface referred to O.D. in feet.*
Hasketon	85	54 [4]	+ 30
Melton—Brewery	28	60 [4]	− 32
Do. Asylum (1)	100	126 [4]	− 26
Do. Do. (2)	15	52 [4]	− 37
Woodbridge—Hayward's	13	48	− 45
Do. Thoroughfare	16	63 [4]	− 47
Do. By river	26	61½	− 35½
Do. Sun Inn	33	52 [4]	− 19
Do. Carter's	77	52	+ 25
Do. Waterworks (1)	120	92	+ 28
Do. Do. (2)	18	193½	−175½
Do. Gas-Works	12	48	− 36
Do. Bredfield Road	126	155 [4]	− 29
Do. Castle Brewery	20	74½ [4]	− 54½
Waldringfield	8	63 [4]	− 55

[1] Mem. Geol. Surv. 1886 (11) p. 40.

[2] The so-called 'Crag' is here nearly three times too thick for any known section or well-boring in the Red Crag.

[3] Slater, 1907 (22) & 1911 (32).

[4] Eocene beds and Crag may also be included.

(*e*) Alde Valley.—The evidence in the much smaller valley of the Alde is naturally not so striking, but a comparison of borings at Saxmundham and neighbouring places serves to show, as Mr. Whitaker hints in the Survey Memoir on the Water-Supply of Suffolk, that here we have a hollow of Drift and Crag cutting through Lower Eocene deposits. It is not necessary for the present purpose to discuss the question as to whether the Crag which rests directly on the Chalk is *in situ* or not, for it is sufficient that Drift extends for a thickness of 103 feet, down to a depth of −3 feet O.D., whereas the usual level in the neighbourhood for the top of the Crag is about +50 feet O.D. It is probable that the borings at Kelsale, higher up the valley, which show 115 and 106 feet of Drift eroding deeply into Crag, confirm the presence of the channel. The Chalk is dipping too rapidly in this extreme eastern part of the county for the channel of Drift to cut down into it. It is only to be expected that, if the channel, as well as the buttressing on spurs already described, is due to glacial action, the phenomena in this part of Suffolk, where the ice-sheet must have become attenuated, should be less well-marked than in the west.

(*f*) Waveney Valley.—Finally, the probability of a buried channel in the Waveney Valley was suggested by the writers of the Geological Survey Memoir on the Halesworth and Harleston area.[1] The Chalk crops out in the valley from Diss to Scole at about +60 feet O.D.; but two borings at Hoxne show Drift with (possibly reassorted) Crag material lying in a hollow of the Chalk, which was here met at −40 feet O.D. The boring at Eye appears to be connected with these two, but it is not easy to account for the Fressingfield boring at 152 feet O.D. reaching Chalk at −118 feet O.D. Indeed, this is the only case in Suffolk where a great depth to the Chalk is met with (Drift and ? Crag) which does not lie in one of the valleys.[2] It is possible that a buried valley is here entirely masked by the Drift now forming the plateau. The levels of the top of the Chalk near Hoxne and Eye are:—Palgrave +105, Stuston +25, Diss +30, Scole +60, Billingford +45, Wortham +110, and Thorndon +33 feet O.D.

With reference to the Dallinghoo boring, which showed 79 feet of Drift, the material cut through being described by the Rev. R. A. Bullen,[3] the late Prof. Seeley remarked that here we had another hidden channel; but this thickness of Drift is normal for the plateau, and proves nothing.

At Euston, in the valley tributary to that of the Little Ouse, running north-westwards from the watershed, a thickness of 224 feet of Drift was recorded, bringing the top of the Chalk to −140 feet O.D. Near by, the Chalk surface occurs at +60,

[1] Mem. Geol. Surv. 1887 (12) p. 3.

[2] But compare also the recent boring at Saham Toney (Norfolk), described by Dr. A. Strahan in the Summary of Progress of the Geological Survey for 1910 (1911) p. 75.

[3] Bullen, 1901 (18) p. 285.

+137, and +146 feet O.D. It is also possible that there is a hollow in the Lark Valley near Lackford, but these north-westward flowing rivers connected with the Wash drainage are outside the area discussed in this paper.

The thicknesses of Drift in all the well-sections in the county have been compared, and all those over 100 feet examined. These latter were found to be on the higher parts of the plateau, where such a thickness would be expected, or in the valleys, where they showed deep channels in older beds.

The conclusion then arrived at is, that in every valley of any size in Suffolk, a deep channel filled with Drift occurs. In some valleys: for instance, the Brett and the Gipping, two such channels appear to be in alignment (unless the one channel takes a very winding course, which is rendered improbable by the evidence of numerous borings on the sides of the valley). It will be noticed that these channels, together with those recorded in the Cam Valley, in the Fen district, the Stort Valley, Hitchin, and Yarmouth, form a roughly radiating series. Those which occur near the sea (Brett, Gipping, Deben) are possibly separated from it by a sill or threshold; but, here again, they may take a circuitous course and maintain their depth to the sea, although the evidence is not at all satisfactory. At Ipswich, where we have a large number of borings, both in the town and in the surrounding country, it is difficult to understand why such a sill should not exist (see fig. 4, p. 602). More borings are needed to outline the form of the channels accurately; but, from those that have been put down, particularly on the sides of the valleys, the channels are seen to be of long narrow form, and in the area discussed all lie in a Drift-covered, recently-glaciated plain stretching to the sea. The data are not sufficient to enable us to draw with certainty the longitudinal profiles of these channels. There is good evidence in the district for believing that the county stood at a higher level in Glacial times; but the evidence is rather against the view that the now-buried channels were carved out by ordinary river-action. There is no uniformity in the depth to which they are cut, as the following comparison shows:—

Channel.	*Depth in feet recorded below O.D.*
Glemsford	−347
Brettenham	− 32
Hadleigh	− 40
Stowmarket	− 5
Ipswich	−117
Woodbridge	−176
River Alde	− 3
Hoxne	− 40
Euston	−140

Moreover, the finding of the rounded flints, unstained and unaltered, at the base of the Ipswich channel, points to pot-hole action, but not that of an ordinary open torrent. We do

not yet know, however, whether a depth of over 400 feet (as at Glemsford) could be excavated by sub-glacial water.

The presence of these channels helps to prove that the valley-system of to-day is older than the valley-glaciers which appear to have formed such deep hollows. It is interesting in this connexion to note that Dr. Emil Werth and others describe in detail similar channels due to the excavating action of sub-glacial water-streams which bubble up and emerge at the snout of the glacier.[1] These are termed Föhrden or Förden in Schleswig-Holstein, Fjärde in Sweden, and Fjorde in Denmark (not to be confused with fiords). The characteristics of these Föhrden are their parallel or radiating arrangement; their long narrow form; their perpendicularity to the ice-edge and to the terminal moraine; their association with deposits of morainic character; the existence of a threshold or sill between them and the sea; and their occurrence on a recently-glaciated, comparatively-low country bordering the sea.[2] Besides their distribution as noted above, they have been studied in Kerguelen by the German Antarctic Expedition of 1901–1903.[3]

The occurrence of deep channels filled with Drift in Suffolk valleys, associated generally with mounds of glacial débris, morainic or glacieluvial gravels, and great masses of Boulder Clay, as well as with intense glacial disturbance, is certainly significant, and is worthy of further attention. It does not seem improbable that here we may have hollows analogous to the true Föhrden, described so graphically and in so much detail by Dr. Werth (indeed, paragraphs from the latter's pen apply equally well to Suffolk conditions).[4]

Dr. Werth, in a letter, tells me that he knows of no examples in North Germany filled entirely with Glacial Drift, but that the complete filling-in of Suffolk channels may be due to the fact that they belong to an older glaciation. Mr. F. W. Harmer has expressed the view that the 'Cannon-Shot' Gravels of Norfolk, with their spherical flints, may be due to the action of sub-glacial water-streams.

VI. Theoretical Questions and General Remarks.

Sir J. B. Phear noted in 1856 that the Gipping was a dip-stream flowing south-eastwards from the Chalk escarpment, which runs generally from south-west to north-east, and examination of

[1] These 'submarine wells' of fresh water emerging as fountains in the Greenland fjords were noted as far back as 1877 by Henry Rink ('Danish Greenland: its Peoples & its Products' London, 1877, pp. 50, 360–63). Such fountains of fresh water burst out with great violence on a sudden fall in the level of marginal lakes of the Greenland ice-sheet. See also W. H. Hobbs, 1911 (30) pp. 175 *et seqq.*

[2] Werth, 1909 (26, 27, 28) & 1912 (36).

[3] *Id.* 1908 (24) pp. 130–48.

[4] For references to further work on Föhrden, see the authors quoted in Werth, 1908 (24) & 1912 (36), as also K. Olbricht, 'Die Exarationslandschaft' Geol. Rundschau, vol. i (1910) p. 59 and references there.

the map of Suffolk (Pl. LIV) shows that the Suffolk rivers are largely dip-streams, although their direction changes from east-north-easterly in the north of the county successively to easterly, south-easterly, and southerly in the south of the county, in consequence of the change in strike of the Chalk. It seems quite likely that many of them are beheaded consequents belonging to a larger drainage-system, which included originally the rivers now reaching the Wash.[1] In the area (south-east of the watershed) with which this paper deals, the form and direction of the rivers and their tributaries would seem to suggest some amount of capture here also, possibly behind an old Eocene escarpment; but the country is now so plastered with Drift that it is almost impossible to obtain evidence of any kind for or against capture. Many of the subsequent tributaries are well developed; but, if capture did take place, the process does not appear to have gone very far. In the case of the Stour, there is a possibility that the river from its source to the Wixoe bend (see Pl. LIV) may be the captured head-waters of the south-eastward flowing consequent stream on which Colchester stands—the Colne. The portion from Wixoe to Long Melford would be subsequent, and the Sudbury portion another consequent, and so on. The watershed between the Colne head-waters and the Stour is only some 80 feet above the river-levels (which are equal, the Stour at Wixoe being 170 feet O.D. and the Colne at Great Feldham 164 feet O.D.), and consists of Upper Boulder Clay and Glacial Sand, there being barely a mile of land between the two valleys. The Drift round about, as shown by well-borings, etc., is often more than 80 feet thick.

The same kind of process may have gone on in the more eastern part of the area, but may have been even less developed. The general rectangularity, which is apparent independently on both contoured maps and uncontoured geological maps, of the course of the Brett Valley (Cockfield to Lavenham consequent, Lavenham to Nedging subsequent, and Nedging to the Stour consequent again), of the Deben Valley (Debenham to Rendlesham consequent, Rendlesham to Woodbridge subsequent, and Woodbridge to the sea consequent again), and possibly of the Alde Valley, is rather significant. The map certainly suggests that the Butley Valley and the upper portion of the Deben Valley were once united, but here, as elsewhere, owing to the mantle of Drift, which is frequently loam, gravel, and sand like that of river-deposits, neither 'gaps' nor river-gravels can be detected. From its very nature, the district does not lend itself to the usual manner of treatment of river-development questions.

The Gipping Valley appears to be purely a consequent one, but it is noteworthy that the watershed between the Gipping (or Orwell) and the much smaller Deben is actually in the east of the town of Ipswich, near the Asylum. Here the small tributary valley which passes eastwards through Foxhall, Brightwell, etc., originates.

[1] Davis, 1895 (15) p. 144.

The Drift-deposits (Upper Boulder Clay and at times Glacial Sand and Gravel) lie in the subsequent and consequent portions of the valleys alike. Where these valleys are winding in character, the sinuosity must have been developed before the oncoming of the Upper or Great Chalky Boulder Clay. It is quite evident that the small streams meandering in these wide valleys at the present time cannot have carved out such features.[1] The present rivers, as insisted on frequently by Mr. F. W. Harmer with especial reference to Norfolk,[2] are out of all proportion to the valleys which they occupy. We have seen that such valleys are certainly either pre-Glacial or early Glacial in age. When, then, was this somewhat mature, low-graded system developed? During the Pliocene Period, the tectonic wave-like movements of the land that now forms East Anglia resulted in a gradual rise southwards and depression northwards, and were doubtless adjustments following the strong Miocene folding of the South of England and the Continent. Reasoning from the boulders found in the Red Crag (London Clay débris, Hertfordshire puddingstone, sarsens, Chalk-flints, masses of Kellaways Rock crowded with *Rhynchonella socialis*, other Jurassic rocks, Bunter pebbles, granites, etc.) the drainage seems to have been towards the east; but, at the end of the Crag Epoch, the drainage appears to have been towards the north or north-west, if we are to believe the Continental geologists, who see in the mica with which the 'Chillesford-Clay river' is loaded, material derived from the Ardennes or even farther south.[3] The Butley, Alde, and more northerly rivers cut through these Chillesfordian Beds: therefore, the present valley-system must have been developed in a doubtless long period, which intervened between the Chillesfordian age and the time when the Glacial Sands and Gravels which lie beneath the Upper Boulder Clay were deposited.

As Prof. J. W. Gregory, Mr. Jukes-Browne, and others have pointed out,[4] the country at the close of Pliocene time must have had an appearance very similar to that which it now presents. The Cretaceous escarpment had by then retreated almost to the position which it now occupies, and was a well-marked feature, as illustrated by the manner in which the Glacial deposits were banked against its front.[5] The outlines of the present drainage would at this time have been etched upon the south-eastward sloping peneplane. Increasing in power, the rivers graded their valleys and some amount of capture may have taken place, possibly behind a secondary Eocene escarpment. Vertical corrasion gave place to lateral corrasion, and the rivers developed their present wide and open valleys (see fig. 5, p. 614), and as

[1] The average annual rainfall of Suffolk for 1862–1902 was 24·5 inches.

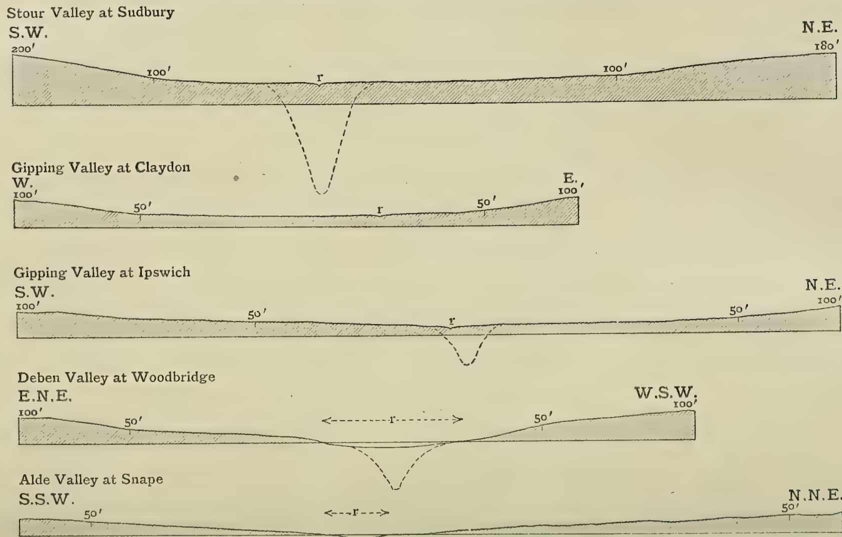
[2] Harmer, 1909 (25) pp. 121 *et seqq.*

[3] Harmer, 1902 (19) p. 447; but see also C. Reid, 'Pliocene Deposits of Britain' Mem. Geol. Surv. 1890, p. 189.

[4] Gregory, 1894 (14) p. 102; Jukes-Browne, 1911 (31) p. 428 (also earlier works).

[5] See also Harmer, 1909 (25) p. 114, etc.

Fig. 5.—*Cross-sections of Suffolk valleys.* (*Scales: horizontal, 4 inches = 1 mile; vertical: 1 inch = 600 feet, or rather more than twice the horizontal.*)



[The sections are each perpendicular to the direction of the river (r). The dotted lines indicate the position and depth of buried channels, but the exact shape of these is not known. The base-line indicates sea-level in each case.]

the streams became sluggish, the wide valleys took their present rather sinuous courses. (It is to be noted that the rivers themselves also meander independently through their alluvial flats, often resting upon Drift in the sinuous valleys.) The valleys are of the shallow trough-like type  described by I. C. Russell.[1]

Thus, before the oncoming of the district-glaciation, the valley-system had reached a fairly mature state, and it is possible that had not this development been now arrested, further grading and capture might have resulted. The great outwashes of sand and gravel from the ice-sheets on the north-west spread over East and South-East Suffolk, extending in places down into the valleys, only to be excavated again for the most part by the streams of water from the same source taking advantage of the channels to the sea which the valleys provided. Thus, the fact that the greater number of the valleys are cut through such sand and gravel, but that sometimes the deposit flows over into them, would be accounted for.

The oncoming ice-lobes themselves would take advantage of the hollows already made in the land-surface, and in an attempt to straighten out the winding valleys, would buttress themselves upon and over-ride each successive projecting spur. Upon the recession of the ice, Boulder Clay was left in all the valleys as well as on the plateau, and was covered by the torrential gravels so well observed in the Suffolk valleys. The high-level glacieluvial gravels also would have been laid down at this time. In fact, it appears that the streams fed by the melting ice were overloaded with detritus, and they deeply filled their valleys with débris, as described by Russell in the glacier-valleys of the Cordilleran region,[2] only, however, to resume the work of excavation and leave the river-terraces and higher-level gravels as evidence of former conditions. It is noteworthy in this connexion that there is a broad development of terrace (a mile and a half wide) at Ipswich, where the valley narrows and takes a sharp bend; similarly also at Sudbury and Woodbridge. (Hence, no doubt, the early settlements and establishment of the various Suffolk towns.) The top of the Gipping terrace roughly follows the 50-foot contour in the lower part of the valley, but rises gradually to the 100-foot contour near Stowmarket: that is, it maintains a fairly constant elevation above the present level of the river. Buried peat and freshwater deposits found in the bed of the Orwell estuary for a length of 7 or 8 miles, and outside the Deben estuary,[3] prove a subsidence since Glacial times of at least 30 feet. Mr. Clement Reid states that the submergence amounts to something between 60 and 80 feet, all through East Anglia.[4] From the terrace-levels the subsidence seems to have been general over the area—there is no evidence of tilting—and it is this subsidence which has buried the lower

[1] Russell, 1898 (17) p. 151.
[2] *Ibid.* pp. 234 & 284; see also G. W. Lamplugh, Q. J. G. S. vol. lxviii (1912) p. 251 (discussion).
[3] Taylor, 1875 (6) p. 82, and 1882 (9) p. 573.
[4] Reid, 1913 (38) p. 22.

portions of Suffolk rivers and turned them into wide open estuaries. The navigation-channels in these estuaries give a clue to the position of the river itself. The rivers, reduced in bulk, with a lower gradient,[1] have deposited small flood-plains of alluvium between their old terrace-outlines, and are now engaged in meandering to and fro in these alluvial flats. Where they touch their old terrace, villages have been built. As previously pointed out, the small streams now occupying these wide open valleys are quite out of proportion to them, and either indicate a good old age (which is not altogether supported by other evidence), or that there has been some interference with their development: namely, that caused by the ice-sheet and valley-glaciers, and a depression which followed the glaciation.

Minor changes have taken place since this last subsidence of the area, and are taking place to-day, being mainly due to the southward tidal drift down the Suffolk coast. This, by damming up river-mouths with shingle, and permitting silting-up to take place, is either tending to form broads, as described by Prof. J. W. Gregory for Norfolk, or diverting the mouths of the rivers southwards. Such deflection is exemplified by the classical case of the Alde, but can be observed to be in process with smaller streams, as well as with the Orwell and Deben.

VII. Conclusions.

(1) The valley-system of Southern and Eastern Suffolk is radiating in character from the watershed parallel to the Chalk escarpment in the north-west, the rivers being largely consequent but partly subsequent in form. The valleys are wide and graded, all angularities having been worn off, and are carved out of all proportion to the size and number of the streams that now occupy them.

(2) On the evidence of the excavation of Red, Norwich, or Chillesford Crags, respectively, by the rivers, the valleys (though they may have been etched earlier) are post-Chillesfordian in age. By analogy with the Waveney and Norfolk rivers, they may be younger than the Contorted Drift (Lower Glacial).

(3) Upper Boulder Clay lies persistently in the valleys, there is Glacial buttressing on projecting spurs, and in each main valley there is a channel filled with Drift. On these three counts the valley-system is older than the Upper Glacial deposits.

(4) There is a similarity of form and origin between the buried channels and the Continental Föhrden, which are admittedly due to sub-glacial drainage.

(5) The present river-system is recovering from a state of arrested development, due to the glaciation of the area (and consequent overloading of the valleys with débris) and the subsidence which followed it.

[1] That of the Gipping is, in its portion from Haughley to Needham, 1 in 713, and in its lower portion (Needham to Ipswich), 1 in 1003.

In conclusion, I have to express my sincere thanks to Prof. W. W. Watts and Mr. W. Whitaker for reading the manuscript and for many helpful hints; to Dr. J. W. Evans for German references, etc.; to Dr. A. Strahan, Director of H.M. Geological Survey, for facilities in obtaining recent well-records; to Mr. F. W. Harmer for his trouble in discussing these questions frequently with me, and for his assistance and direction in Norfolk field-work; to Mr. Thomas Miller, C.E., Mr. C. W. Oldham, and Mr. T. J. Warner, of Ipswich, for records of new borings; and particularly to my friend Mr. George Slater, of Ipswich, for permission to use freely his admirable material on East Anglian glaciology.

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(27) 1909. E. Werth.—'Zur Entstehung der Förden' Zeitschr. Deutsch. Geol. Gesellsch. vol. lxi, pp. 401–404.
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(30) 1911. W. H. Hobbs.—'Characteristics of Existing Glaciers' New York.
(31) 1911. A. J. Jukes-Browne.—'Building of the British Isles' 3rd ed. London.
(32) 1911. G. Slater.—'Excursion to Ipswich' Proc. Geol. Assoc. vol. xxii. p. 11.
(33) 1912. P. G. H. Boswell.—'Report of an Excursion to Ipswich & the Gipping Valley' Proc. Geol. Assoc. vol. xxiii, p. 229.
(34) 1912. Rev. E. Hill.—'The Glacial Sections round Sudbury (Suffolk)' Q. J. G. S. vol. lxviii, p. 23.
(35) 1912. W. Hill.—'Report of an Excursion to the Hitchin & Stevenage Gap' Proc. Geol. Assoc. vol. xxiii, p. 217.
(36) 1912. E. Werth.—'Zur Föhrdenfrage' Geol. Rundschau, vol. iii, pt. 3, p. 164.
(37) 1913. P. G. H. Boswell.—'Notes on the Chalk of Suffolk' Journ. Ipswich & District Field Club, vol. iv, pp. 17–26.
(38) 1913. C. Reid.—'Submerged Forests' Cambridge.

EXPLANATION OF PLATES LIV & LV.

Plate LIV.

Map of Suffolk, showing the river-systems and the position of the top of the Chalk, on the scale of 8 miles to the inch, or 1 : 506,880.

Plate LV.

[All figures on the scale of 1 inch to the mile, or 1 : 63,360.]

Fig. 1. Contoured map of the Gipping Valley, showing projecting spurs where disturbance of beds occurs.

2. Contoured map of the Brett Valley, showing the same phenomena as fig. 1.

3. Contoured map of the Stour Valley (upper part), showing the same phenomena as figs. 1 & 2.

Discussion.

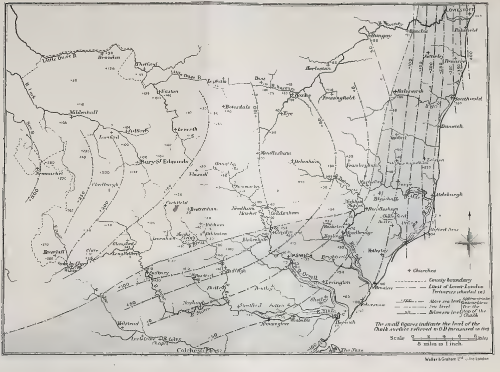
Mr. F. W. Harmer said that he had listened with great pleasure to the paper, the subject of which was both interesting and important, and he congratulated the Author very cordially on the way in which he had worked it out. For many years the Eastern Counties had been too much neglected by field-geologists. It was, therefore, the more gratifying that at Ipswich, which had been lately so much to the front, the Author and his coadjutor, Mr. Slater, were setting themselves seriously to carry on the work of which the speaker's old friend and master, the younger Searles V. Wood, laid the foundations more than fifty years ago. That, in some matters of detail, the latter's conclusions might need reconsideration would not come as a surprise, but to those who could remember the condition of East Anglian glaciology in 1860, the marvel was that they required so little.

The speaker had long doubted, for example, as the Author did, whether the Contorted Drift of the Cromer coast ever reached as

YSTEMS AND THE POSITION OF THE TOP OF THE CHALK.

Weller & Graham Ltd Litho, London

MAP OF SUFFOLK SHOWING THE RIVER-SYSTEMS AND THE POSITION OF THE TOP OF THE CHALK.



far south as Wood supposed. Taken as a whole, however, Wood's foundations were well and truly laid, and his successors may safely build on them.

The question of the origin of the valley-system of East Anglia should be studied as a whole, and over as wide an area as possible. If it were possible to ascertain the conditions obtaining in one part of the region, it would not be unreasonable to draw conclusions as to what was going on at the same time in another. The facts to be observed in Norfolk, where the evidence was clearer, might therefore throw light on those adduced by the Author from the sister county.

In the speaker's opinion, East Anglia was twice invaded by ice; and first from the north, by the Great Scandinavian glacier. To this invasion was due, not only the Contorted Drift of the remarkable and abrupt ridge which crosses the north-eastern portion of Norfolk from west-south-west to east-north-east, attaining a maximum thickness of 300 feet, but also the uncontorted beds of brick-earth equivalent to it which occur over the lower and flattened region towards Norwich. The latter, the speaker considered, represented the moraine profonde of the North-Sea ice during its maximum extension; the former (the contorted part) a terminal moraine at some stage of its retreat.

Now, it seems clear that when the North-Sea ice crept over the country from the Cromer coast to the latitude of the Waveney Valley and beyond, the present valley-system of East Norfolk could hardly have been in existence: any pre-Glacial elevations then existing would have been levelled down by the ice, and any pre-Glacial depressions levelled up, or filled in by the morainic detritus brought by it. Moreover, the North-Sea Boulder Clay never occurs in this region as a valley-deposit; on the contrary, the valleys, as, for example, those of the Yare and Wensum at Norwich, and of the Waveney at Beccles, are distinctly shown to have been cut out of it.

The second invasion, possibly separated from the first by a considerable interval, was that of the great inland glaciers from the north-west, to which the Chalky Boulder Clay, with its Neocomian and Jurassic detritus, was due. The latter not only overspreads the higher ground, but, as we all know, wraps the sides of the present valleys, descending to the bottom, sometimes considerably below sea-level.

The excavation of the Norfolk valleys took place, therefore, after or during the retreat of the North-Sea ice-sheet, but before the deposition of a part at least of the Chalky Boulder Clay. It may have been due, not improbably, to the action of torrential water during the retreat and melting of the ice of the first glaciation.

The Author had found similar conditions in Suffolk, as Wood and the speaker did when they were mapping the county in the sixties; but here the relation of the Chalky Boulder Clay to the North-Sea Drift is not so clear, owing to the absence of the latter from a great part of the county. This subject was dealt with in a paper which the speaker read before the Society in 1866.

He considered that there remained much work still to be done in the district in question. The detailed investigation which Mr. Slater and the Author were making could not fail to bring to light many new and interesting points.

The Rev. Edwin Hill said that he was pleased that this work had been taken in hand by a worker possessed of such qualifications. He entirely agreed with the view adopted as to the age of this valley-system; and he was not without hope that indications of earlier stages might yet be found. Further light on the buried channels was to be wished for, but there were obvious difficulties in the way of obtaining the information desired.

The Author, in reply, agreed entirely with Mr. Harmer's conclusions, but thought it best to use caution in reasoning by analogy. Lack of time prevented the full discussion of the extent of the buried channels of Drift. It was possible that the hollows ended abruptly, as would be expected if they were eroded by sub-glacial water-streams. If the channels were continuous to the sea, their courses would be difficult to follow, and must be somewhat sinuous, departing from the present valleys. With reference to the well-borings, a maximum of facts was recorded, and a minimum of conclusions drawn, great caution being necessary in the interpretation of the records. Reasons for the belief that the Contorted Drift does not occur in Southern Suffolk were given briefly in the paper. In conclusion, the Author thanked the Fellows for the reception accorded to his paper.

27. *On the* Petrology *of the* Kalgoorlie Goldfield (Western Australia).

By James Allan Thomson, M.A., D.Sc., F.G.S., Palæontologist to the Geological Survey of New Zealand.

(Read May 7th, 1913.)

Contents.

Abbreviations used.

E. East Coolgardie Goldfield. The number refers to the register of gold-mining leases.
G.M. Gold mine.
G.M.L. Gold-mining lease.
G.S.M. Geological Survey Museum. The number refers to the register of rocks in the possession of the Geological Survey of Western Australia.

I. Introduction.

The goldfields of Western Australia may be conveniently considered as forming a series lying between two extreme types. At the one end are fields such as Southern Cross and Coolgardie, lying within the contact-aureoles of granitic intrusions: their rocks are intensely

altered by contact, and consist of foliated hornblende and tremolite-talc-schists alternating with massive amphibolites which show complete mineralogical reconstitution; their auriferous deposits are often of phenomenal richness, but are sporadically distributed, and the effects of hydrothermal alteration on the walls of the veins are, in general, slight. Norseman may be cited as an example of a field lying partly within and partly without the aureole of a granite, the apophyses of which, nevertheless, play a considerable rôle, even in those parts that are unaffected by contact-alteration. Kanowna is composed of rocks showing no trace of contact-alteration, but it, too, is dominated by dykes of quartz-porphyry. At the other end lies Kalgoorlie, an area in which neither granites nor quartz-porphyries play any part. The rocks are mainly amphibolites and serpentines showing little structural metamorphism, but a distinct feature is the presence of albite-porphyry and porphyrite-dykes; the auriferous deposits are more regular in distribution than in the other fields, and the metasomatic alterations of the country-rock are very intense.

In this paper the rocks of Kalgoorlie, which I have had the opportunity of studying in the field, are described in detail, and, in addition, comparisons are made with similar rocks from other parts of the State, based on the study of specimens kindly supplied by Mr. A. Gibb Maitland, Director of the Geological Survey of Western Australia. Kalgoorlie appears to be more complex than other fields of similar type, and it is possible that some of the problems which it presents will become clearer if they can be attacked in detail in areas of simpler constitution.

The mines of Kalgoorlie are situated on a broad ridge about 4 miles long by a mile in width, trending in a north-north-westerly and south-south-easterly direction. The southern end contains the rich mines which have made the goldfield famous, and, on this account, has been popularly termed 'The Golden Mile,' or briefly 'The Mile.' The northern part, which is but moderately auriferous, is locally referred to as the 'North End.' These local names will be employed in this paper. The town of Kalgoorlie occupies the floor and eastern slopes of a valley to the west of the 'North End'; farther south, the suburb of Boulder lies in the same valley to the west of 'The Mile,' and hence 'The Mile' is also spoken of as the 'Boulder Belt.'[1] This valley and a similar one limiting the ridge on the eastern side are both deeply filled with alluvium and wind-blown material; while a mantle of surface-deposits extends for a considerable distance up the sides of the ridge itself, in some places completely enveloping it. Nearly all the highest points are formed of hard, red, ferruginous laterite resting on an earthy white material resembling kaolin, but the laterite is not confined alone to the high points. Smaller irregular

[1] Boulder, the suburb of Kalgoorlie, must not be confused with Boulder City (Colorado). The paper by Mr. T. A. Rickard, on 'The Veins of Boulder & Kalgoorlie' Trans. Am. Inst. M. E. vol. xxxiii (1903) pp. 567–77, refers to the American telluride-field.

or wall-like hillocks are due to the projection of reefs of banded jasper, rising through the surface-deposits. Wherever the solid rocks of the ridge crop out at the surface, or are exposed in shallow trenches, they are nearly always oxidized, with the exception of a few amphibolites. In these circumstances geological field-work is rather difficult, and were it not for the material which may be collected in the dumps of old mines and prospecting shafts, added to the artificial sections displayed in the extensive mine-workings in depth, the complexity of the field would never be suspected, and geological mapping would be impossible.[1]

The ridge is composed of elongate masses of massive or subschistose rocks, each trending in a north-north-westerly and south-south-easterly direction, and the floors of the valleys on each side appear to possess the same character. Where schistosity is developed, the planes of foliation have the same general trend as the rocks themselves, with a steep dip averaging 60° west-south-westwards. The rock-junctions, where not faulted, appear to possess the same direction of inclination; but on this point few positive observations can be made, for the majority of rock-junctions traversed by mine-workings prove to be faults. The central mass of the ridge is a large dyke or sill of altered, coarse, intrusive quartz-dolerite, which traverses the higher hills of the 'North End' in a band 200 yards to a quarter of a mile wide, and spreads out in 'The Mile' to form a boss-like mass measuring about half a mile in diameter. Three other dykes leave the boss, one running for about a mile from the north-east side to lose itself under the surface-deposits of the eastern valley, the others being practically the southward prolongations of the northern two, and running for some distance in the direction of Hannan's Lake. On most sides the quartz-dolerites are surrounded by fine-grained amphibolites and greenstones of somewhat variable character, presumably the country-rocks into which the dykes are intrusive. In the eastern part of the 'North End' a large intrusion of ultrabasic rocks approaches closely the main quartz-dolerite dyke, but is separated by a thin band of fine-grained amphibolite. On the somewhat scanty evidence of widely-separated dumps on the flats west of the ridge, it appears that another ultrabasic intrusion in the fine-grained amphibolites runs parallel to the quartz-dolerite at some little distance from it. Farther west in the Kalgoorlie-Boulder valley the few dumps that are available reveal only porphyrites, but whether there is a broad band of this rock or several separate dykes remains uncertain. The quartz-dolerite of 'The Mile' is intersected by two thin dykes of albite-porphyry, which have the common north-north-westerly and

[1] It is unfortunately impossible to reproduce with this paper a geological map prepared by Dr. J. M. Maclaren and myself, since the information which it contains as to the distribution of the rocks and lodes, and more particularly as to the faulting that they have undergone, is the exclusive property of the group of mining companies on whose behalf it was prepared. Nevertheless, the reservations thus made concerning the exact boundaries of the rocks do not materially affect the discussion of the phenomena described in this paper.

south-south-easterly trend of the field; and similar dykes are known, both in the fine-grained greenstones and in the eastern mass of peridotite. South of 'The Mile' the tongue of rock between the two southern dykes of quartz-dolerite is occupied, so far as the dumps show, by albite-porphyry and graphitic schists in numerous alternations.

Slaty rocks, which present superficially the appearance of sedimentary origin, occupy parts of the valleys both east and west of the main ridge, and are well exposed in quarry-pits. They are really more siliceous than true slates, and never show traces of clastic origin or contain any indications of fossils. Similar slaty rocks are found on each side of the many jasper-reefs which intersect the igneous rocks of the field, and are undoubtedly of igneous origin: wherefore, until some criteria are found for distinguishing the two sets of rocks, it is unsafe to assert that any sedimentary rocks occur in the valleys. An undoubtedly sedimentary series, composed of thick beds of sheared conglomerates, interstratified with reddish and chocolate-coloured grits and sandstones, occupies a high ridge at Kurrawang, about half way between Kalgoorlie and Coolgardie. In strike and dip it conforms to the foliated igneous rocks of Kalgoorlie, but the lack of continuous exposures in the intermediate ground makes it impossible to say what is the geological relationship of the two series. The pebbles in the conglomerates consist chiefly of liver-coloured quartzites, hæmatite-jaspers, and albite-porphyries, the last-named being very similar to those of Kalgoorlie, whence the inference may be drawn that the Kurrawang Series is the later.

The gold of Kalgoorlie is contained mostly in 'lode-formations,' which are shear-zones impregnated with sulphides and tellurides. They may occur in any class of rock, but those in the quartz-dolerites are the most regular and the richest, the other two most favourable rocks being the fine-grained greenstones (calc-schists) and the schistose derivatives of the peridotite. In the 'North End' the lodes in the quartz-dolerite are of low grade, but they are often crossed by small quartz-reefs carrying rich ore, though without tellurides.

II. Historical Review.

The earliest geological notices of Kalgoorlie are found in general accounts of the parent Coolgardie field, and contain few observations of value. At a later date many contradictory determinations of the country-rock of the lodes, based solely on the inspection of hand-specimens, were made by visiting mining engineers, but their enumeration here would serve no useful purpose. The earlier microscopical identifications were made by petrologists who had not the advantage of collecting their own specimens; and, considering the excessive alteration displayed by the rocks near the lodes, it is not surprising that views widely at variance were put forward. The subjoined correlation (on pp. 626–27) of the various classifications proposed will render the following account of them more easily intelligible.

The first description of the microscopical characters of rocks from Kalgoorlie was made by Mr. G. W. Card,[1] who examined specimens collected by Prof. Frecheville and Mr. Pittman. The amphibolites, in his opinion, had little or no connexion with the auriferous country-rock or with the ore-deposits, and consequently received little notice. The mineralogical composition and structure of the other rocks left him in no doubt of their igneous origin and close relationship. Reasoning mainly from two rocks—the one a felspar-porphyry, the other an apparently acid rock containing large crystals of quartz and felspar—he concluded that he was dealing with an acid complex of varying texture and structure, granitic in places and felsitic in others. Since the abundant chlorite of the supposed granitic rocks (in reality, derivatives of quartz-dolerite) could not be ascribed to the alteration of some earlier ferromagnesian mineral, he described it as a 'pigment,' and supposed that it had been introduced into the rocks by solutions. Mr. Card's description of the mode of occurrence of the quartz in the quartz-dolerite derivatives as 'islands' in an 'archipelago' was very happy, and has been freely adopted in this paper.

About the same time, Prof. W. W. Watts[2] contributed a note on a rock from a locality south of the Great Boulder Main Reef G.M., describing it as a

'quartz-diorite with (?) two felspars, green altered hornblende, quartz, and micropegmatite.'

This rock was doubtless a quartz-dolerite amphibolite, the uralite being considered by Prof. Watts as original.

In the same year Mr. G. J. Bancroft[3] recorded the presence of two dykes, the rocks of which were determined by Prof. J. F. Kemp as

'pyroxenite composed mostly of tremolite or actinolite.'

The country-rock of the rich area, which had a bluish tinge, was described as an altered basic eruptive, now containing serpentine and olivine. A greenish unproductive rock was said to be similar, except for the occurrence in it of olivine. The bands of graphitic schist were described, again on the authority of Prof. Kemp, as

'true slate, probably an altered and metamorphosed clay-rock.' (*Loc. cit.*)

In a separate paper Prof. Kemp[4] gave more detailed descriptions of the pyroxenites and graphitic schists.

[1] 'Report on some West Australian Rocks' Ann. Rep. Dep. Mines, N.S.W., for the Year 1897, Sydney (1898) p. 192; 'Notes on the Country Rock of the Kalgoorlie Goldfield' Rec. Geol. Surv. N.S.W. vol. vi (1898) pt. 1, pp. 17–42.

[2] In E. Halse, 'Observations on some Gold-bearing Veins of the Coolgardie, Yilgarn, & Murchison Goldfields, Western Australia' Trans. Inst. Min. Eng. vol. xiv (1897–98) pp. 289–311.

[3] 'Kalgoorlie (Western Australia) & its Surroundings' Trans. Am. Inst. M. E. vol. xxviii (1898) p. 92.

[4] 'Geological Occurrence & Associates of the Telluride Gold-Ores' Mineral Industry, vol. vi (1898) pp. 318–19.

PROPOSED CLASSIFICATIONS OF

Classification adopted in this paper.			LARCOMBE, 1911.
	Original state of rocks.	*Present state of rocks.*	
I.	Sediments.	Kurrawang Series (sheared conglomerates, grits, etc.).	Older sediments.
II.	Lavas and tuffs (?).	(*a*) Fine-grained amphibolites.	
		(*b*) Fine-grained greenstones and greenstone-schists.	
		(*c*) 'Calc-schists.'	Metamorphic tuff.
III.	Intrusive rocks. A. Peridotites.	Serpentines, talc-magnesite-schists, magnesite-rocks, fuchsite-magnesite rocks.	Serpentine.
	B. Pyroxenites.	Hornblende-rocks.	
	C. Hornblende-dolerites.	Lustre-mottled amphibolites.	
	D. Gabbros or dolerites.	Epidiorites.	
	E. Quartz-gabbros or quartz-dolerites.	(*a*) Epidiorites with micropegmatite.	
		(*b*) Chloritic rocks with micropegmatite (albitized greenstones) and schistose representatives.	Quartz-andesite. Aphanite.
		(*c*) Bleached greenstones with micropegmatite and quartz-sericite-carbonate-schists.	
	F. Porphyrites.	Porphyrites.	Porphyrites (?).
	G. Albite-porphyries.	Albite-porphyries.	Felspar-porphyries.

Mr. H. B. Corbin[1] was the first to doubt the sedimentary origin of the graphitic schists. He showed that certain supposed fossils were only pyritous nodules, and explained the slaty rocks as due to the contact-alteration of a porphyry by a 'diorite'-dyke. His explanation, however, did not gain acceptance, and for twelve years the views put forward by Prof. Kemp held the field.

In 1902 the Geological Survey of Western Australia published a map of Kalgoorlie by Mr. A. Gibb Maitland & Mr. W. D. Campbell,

[1] 'Notes on the Graphitic Slates & Associated Rocks in the Kalgoorlie District' [& Discussion thereon] Trans. Roy. Soc. S. Austral. vol. xxii (1898) pp. 72–75.

THE ROCKS OF KALGOORLIE.

GIBSON, 1911.	SIMPSON, 1902.	Earlier determinations.
Ancient sediments.	Older sediments.	Conglomerates (Chewings).
Fine-grained amphibolites (older greenstones).	Amphibolites and their derivatives (in part).	
Calc-schists.		
Peridotites.	Serpentines.	Talc-schist (Maitland).
Basic amphibolites.	Amphibolites and their derivatives (in part).	Pyroxenite (Kemp).
Felspathic and acid amphibolites.		Amphibolites (Göczel, Card, Schmeisser, Campbell). Quartz-diorite (Watts).
Quartz-diabase.		Acid eruptives (Card). Basic eruptives (Rickard). Diabase (Hoover). Quartz-andesite (Judd).
Porphyrites.	Porphyrites.	Porphyrites (Campbell).
Felspar-porphyries.	Felspar-porphyries.	Soda-felsite (Maitland). Felspar-porphyry (Card). Felsite (Campbell).

on the scale of 10 chains to an inch (8 inches to a mile). The classification on which the map was based was as follows:—

- Recent superficial deposits.
- Dry blown patches.
- Laterite (ironstone conglomerate).
- Slates and schists.
- Quartzites and graphitic slates.
- Felsite (?).
- Amphibolite, massive (with hornblende).
- Do. do. (with chlorite).
- Do. do. (with actinolite).
- Do. foliated.
- Porphyrite.
- Mica-schist [transmuted porphyrite (?)].
- Peridotite.

In this map, the jasper-reefs were coloured as quartzites, being evidently therefore considered as sediments, and an extraordinary number of 'felsite'-dykes were shown accompanying the jaspers. The peridotite-intrusion in the 'North End' was not recognized, and the distinctions made among the amphibolites did not correspond to any very clear natural divisions in the rocks themselves. Consequently, the publication of the map had little or no influence in directing mining operations, more particularly as no explanatory memoir accompanied it.

The rocks collected during the preparation of the map were examined and described in the same year by Mr. E. S. Simpson[1] in a short but concise paper, illustrated by numerous chemical analyses. The rocks were classified as follows:—

I. Amphibolites and their derivatives (massive greenstones, chlorite-schists, massive and foliated siderite-rocks).

II. Newer eruptives { Felspar-porphyry. Porphyrite. Peridotite.

III. Older sediments.

IV. Newer sediments. Chemical:—Salt, travertine, siliceous sinter, and laterite.
Mechanical:—Sand, clay, and ironstone-gravel.

That writer's treatment marked a great advance in Kalgoorlie petrology, not only because of its comprehensive character, but also on account of the importance conceded by it to the amphibolites. Dr. Vogelsang,[2] who had previously made a study of the rocks of other Western Australian goldfields, had suggested the derivation of the amphibolites occurring in them from diabases, and Mr. Simpson applied this explanation to those of Kalgoorlie, pointing out that they were too poor in silica to be termed diorites. He further recognized the close connexion between the amphibolites and the greenstones, rejecting Mr. Card's explanation of the latter as altered granites, a view which the analyses abundantly disproved. His failure to distinguish between the older and the younger amphibolites and greenstones may probably be put down to lack of opportunity of studying the field-relations in sufficient detail. The differences of interpretation on some points between Mr. Simpson and myself are fully discussed below.

Until quite recently, subsequent authors (Krusch, Lindgren, Maitland, etc.) have, in general, followed Mr. Simpson; but Mr. T. A. Rickard,[3] writing about the same time, quoted a determination of the dominant rock by Prof. J. W. Judd as a 'highly-altered quartz-andesite,' a view that might easily be taken after study of

[1] 'Notes from the Departmental Laboratory: Rocks of Kalgoorlie' Bull. Geol. Surv. W. Austral. No. 6 (1902) pt. 2, pp. 62–79.

[2] In K. Schmeisser, 'Die Goldfelder Australasiens' Berlin, 1897, p. 45 (English transl.: The Goldfields of Australasia, London, 1898, pp. 63–83).

[3] 'The Veins of Boulder & Kalgoorlie' Trans. Am. Inst. M. E. vol. xxxiii (1903) pp. 574–75.

only a few specimens of the more obscure greenstones. Dr. L. J. Spencer[1] cast some doubt on the derivation of the lode-matter from an amphibolite, being deceived by the thorough-going chemical alteration which the bleached greenstones and ores have undergone.

'No hornblende was detected on any of the British Museum specimens [of telluride-ores], and in published analyses (Simpson, 1902) of these rocks the small amount of magnesia in the portion of the rock insoluble in hydrochloric acid indicates that not much, if any, hornblende can be present. Bands of hornblende-schist are no doubt sometimes present in the sericite-schist. Much confusion between observed fact and theory has been occasioned by the attempts of various authors to explain the origin of these schists.' (*Op. cit.* p. 281, footnote.)

During 1909–10, while Dr. Maclaren and myself were engaged in mapping the field, geological work was also being carried on by Mr. C. O. G. Larcombe, of the Kalgoorlie School of Mines, and Mr. C. G. Gibson, of the Western Australian Geological Survey. A limited exchange of views took place, and the resulting classifications[2] show, in consequence, some approximation to each other (see Table, pp. 626–27). Mr. Gibson has not yet presented the petrographical details that led to his conclusions, but it may be noted that he failed to recognize the original rocks from which the amphibolites were derived, while correctly assigning the greenstones to quartz-diabase. Mr. Larcombe dealt mainly with the rocks of 'The Mile,' and, in consequence, has failed to realize the intrusive nature of the quartz-dolerite, which he terms 'quartz-andesite.' Neither of these writers has recognized the albitization of the greenstones, nor the close relationship between the albite-porphyries and the quartz-dolerites.

III. Descriptive Petrography.

Through the kindness of Mr. A. Gibb Maitland, Director of the Geological Survey of the State, all the rock-specimens and microscopic sections of Kalgoorlie rocks in the Survey collections were placed at my disposal. By this means it has been possible to identify the rocks of which analyses had previously been published, and to use these analyses in connexion with the classification here adopted. Including the Survey collection, about 500 thin sections have been examined in the preparation of this paper, this apparently excessive number being necessitated by the great variations which the metasomatized quartz-dolerites and peridotites display, and by the lithological resemblances between altered rocks of very different origin. Obviously, for purposes of brevity and clearness, only the more conspicuous types can be described here, and preference

[1] 'Mineralogical Notes on Western Australian Tellurides: the Non-Existence of "Kalgoorlite" & "Coolgardite" as Mineral Species' Min. Mag. vol. xiii (1902–1903) pp. 268–90.

[2] C. G. Gibson, 'Notes on the Principal Geological Features of the Kalgoorlie Goldfield' Ann. Rep. Geol. Surv. W. Austral. for 1910 (in Ann. Rep. Dept. Mines, W.A., published 1911) pp. 115–23 and map; C. O. G. Larcombe, 'The Geology of Kalgoorlie (Western Australia) with special reference to the Ore-Deposits' Proc. Austral. Inst. M. E. vol. v, No. 2 (1911) pp. 1–312.

is given to those which betray their origin most clearly. Many of the rocks are best described as being of a nondescript character.

The comparisons made with similar rocks occurring elsewhere in Western Australia are based mainly on the study of specimens kindly presented by Mr. Gibb Maitland, many of which were also analysed by the officers of the Survey. They show very clearly the general similarity of the massive amphibolites of the different goldfields, and lead to the hope that each field will prove capable of resolution into its original constituent rocks after careful petrological study.

The term greenstone is used throughout for rocks in which chlorite and carbonates predominate to the exclusion of hornblende and epidote or zoisite—that is, it is used in contradistinction to the term amphibolite and in the sense of the German grünstein. This is, no doubt, a restriction of the general usage; but it has this justification, that it obviates the necessity for a new term, and meets a definite need. It is only in rare cases that it is not possible to decide at once, on an inspection of the hand-specimen, whether a given rock is an amphibolite or a greenstone, and hence the wider use of the latter term is unnecessary. The Kalgoorlie greenstones are not mere surface-modifications of the amphibolites, but retain their characteristics to the greatest depth to which mining has been carried: that is, over 2500 feet. The distinction between amphibolites and greenstones (as here restricted) is of the utmost economic import in Western Australia.

(*a*) The Sediments.

There is some difficulty in obtaining specimens of the sediments suitable for microscopic study. In the first place, the rocks themselves, with the exception of the conglomerate-bands, are seldom exposed at the surface. As they have not proved auriferous, but little exploratory work has been done on them, and there is an absence of dumps from which fresh material may be obtained. Moreover, in the immediate neighbourhood of Kalgoorlie, cherty, slaty, and graphitic rocks of undoubtedly igneous origin are so abundant, that one hesitates to accept any rocks of similar appearance as sedimentary. The processes of alteration have so far obscured the peculiarities of the igneous rocks that no microscopic criteria exist for distinguishing the two groups.

Where undoubted sedimentary rocks crop out, as in the ridges south-east of Kurrawang, they are of much coarser texture than the slaty varieties above mentioned, and vary in character from grits to coarse conglomerates. At the surface, they are generally reddish or purple from the presence of oxide of iron. Sections show that the grits consist chiefly of quartz and felspar in subangular or elliptical grains, with their longer axes parallel. The felspars belong both to orthoclase and to acid plagioclase, and along with quartz often show strain-shadows. There are, in addition, similarly-shaped areas of cataclastic quartz and felspar.

Next in abundance is biotite, partly in stout flakes irregularly distributed, partly in thin plates with a well-marked parallel structure. It appears to be of authigenous character. A fair amount of chlorite seems to result from the alteration of the biotite. A little epidote, carbonates, and iron-ore complete the list of minerals. The rocks have evidently been subjected to a considerable amount of shearing.

The matrix of the conglomerates is of similar composition, and is distinctly schistose. The enclosed pebbles consist chiefly of hæmatite-jaspers, liver-coloured quartzites, and quartz- and albite-porphyries. The last-named are indistinguishable from the albite-porphyries found at Kalgoorlie.

A conglomerate of somewhat similar character, traced by Dr. Maclaren in a ridge $19\frac{1}{4}$ miles north-north-east of Kanowna, on the Kurnalpi Road, differs from the Kurrawang Conglomerates in containing pebbles of amphibolites, mostly of basic character.

(*b*) The Fine-Grained Amphibolites.

These rocks are found in various dumps, chiefly in the 'North End' and on the western side of the main dyke of quartz-dolerite, but also less commonly on its eastern side. The known occurrences are too isolated for us to judge by these alone of the geological form. The rocks pass gradually into fine-grained greenstones, which have a wider distribution, occupying most of the Kalgoorlie ridge outside the main quartz-dolerite dyke.

Unlike the coarser amphibolites described below, the fine-grained amphibolites retain no recognizable relict-structures. Their geological history cannot, therefore, be ascertained by microscopic study in the Kalgoorlie field. Mineralogically, they have the composition of amphibolites derived from basalts or more basic rocks.

If they were of very limited distribution and confined to the immediate neighbourhood of the coarser intrusive rocks, it would be possible to consider them as the result of alteration of the chilled margins of these intrusives; but, along with the fine-grained greenstones derived from them, they occupy an area considerably broader than the widest dyke known in the field, so that this explanation becomes impossible, although perhaps some of the rocks here described are such chilled margins. Similar fine-grained amphibolites and greenstones, however, attain a considerable development in other districts where coarse intrusives are unknown: as, for example, the 'Six Mile,' Kanowna. Since they apparently result from the alteration of basic igneous rocks, the most probable explanation of their origin is that they represent an older series of lavas and tuffs into which the coarser amphibolites are intrusive. A distinction may thus be made between the older and the younger amphibolites and greenstones.

Mineralogically, the amphibolites consist chiefly of hornblende and zoisite, with smaller amounts of felspar, sphene, chlorite, carbonates, and quartz. The hornblende is a pale variety, except

where the rocks are contact-altered, and is generally disposed in small tufts with very irregular boundaries to the individual crystals. The spaces between the tufts are filled with very fine aggregates of zoisite, sphene, and quartz, and these minerals also occur in nests and venules along with chlorite and carbonates. Felspar occurs generally in platy crystals giving long lath-like sections, in which no extinction-angles greater than 10° have been observed for symmetrically-disposed albite-twins. In many of the rocks felspars appear to be absent, but have possibly escaped detection in the fine aggregates of quartz and zoisite.

Fine-grained amphibolites showing contact-metamorphism are found in some dumps near Monument Hill, 3 miles south of Boulder Post-Office; and, as these dumps are surrounded on all sides by dumps containing porphyrite, it is probably to the agency of the latter rock that the contact-alteration must be ascribed. The hornblende is no longer pale, but is vivid green with bluish tones, similar to those displayed by the actinolite-veins which ramify through the Cornish spilites in the contact-aureole of the Land's-End granite. Both the hornblende and the clinozoisite are reconstructed into larger and more euhedral crystals, and the sphene occurs no longer in granules but in wedge-shaped prisms. Biotite has developed to some extent within the hornblende, while the clinozoisite contains kernels of orthite. Finally, the rocks are penetrated by venules of quartz, clinozoisite, and actinolite. All the above-described features are characteristic of contact-alteration in amphibolites. An additional feature in some of the specimens is the presence of small ellipsoidal white patches, measuring $2\frac{1}{2}$ cms. in their greatest diameter, which give a concretionary aspect to the rock. These consist of hornblende and zoisite, like the rest of the rock; but the hornblende is in less amount and in stouter prisms, while zoisite preponderates as a dense mosaic.

Fine-grained amphibolites, in many respects similar to those of Kalgoorlie, have a fairly-wide distribution in Western Australia. Among the rocks which I described in 1909 from the West Pilbara Goldfield,[1] there are three that may be classed here (G.S.M. 6405 & 6415, Weerianna; 6429, 2 miles north-east of Mount Marie, near Roebourne). Because of the lack of *relict-structures* and the greater metamorphism which they showed in comparison with the coarser amphibolites, it was then suggested that they formed an older series, comparable with the Lewisian of Scotland. A re-examination of these rocks in the light of the experienced gained at Kalgoorlie shows that the greater structural metamorphism is due to contact-alteration, and that they were probably before then fine-grained amphibolites similar to those of Kalgoorlie. A better analogy of their probable relation to the coarse-grained amphibolites is illustrated by that of the Old Lizard Head Series to the Lizard serpentines and gabbros.

In the Cue and Day-Dawn Goldfields, Mr. H. P. Woodward &

[1] Bull. Geol. Surv. W. Austral. No. 33 (1909) pp. 132, 137, 141, & 143; also fig. 50, p. 141.

Mr. E. S. Simpson have described a series of andesites capping one of the hills. They are stated to be vesicular, amygdaloidal, sometimes showing flow-structure and sometimes brecciated.[1] Some confusion of very different rocks has evidently taken place; G.S.M. 6973, Crême d'Or G.M.L. 389, is a very fresh igneous rock: from the published analysis it would seem to be a basalt rather than an andesite, and in all probability it is a comparatively recent dyke-rock; the other specimens which I have seen (G.S.M. 74 & 7307, Cue Hill; 3823, New Princess Extended G.M., Cue) are fine-grained zoisite-amphibolites, considerably contact-altered, and sometimes brecciated and recemented by a coarse matrix of hornblende and zoisite. An analysis of one of them is quoted below.

Other localities where the fine-grained amphibolites have been recognized may be briefly cited:—Cumberland G.M., Norseman; Laverton (G.S.M. 6537); Lennonville (G.S.M. 3966); Mount Malcolm (G.S.M. 4425); and Kimberley (G.S.M. 3749).

No analyses from Kalgoorlie are available, but there are two of similar rocks from other goldfields, which agree closely enough with the analysis of the Ovifak basalt.

	I.	II.	III.
SiO_2	48·10	48·06	48·04
TiO_2	0·41	0·90	0·39
Al_2O_3	15·41	16·21	13·13
Fe_2O_3	10·32	0·89	6·89
FeO	4·33	10·37	11·14
MnO	0·05	0·59	0·11
MgO	6·38	6·67	5·17
CaO	12·73	11·37	10·87
Na_2O	2·11	2·50	2·83
K_2O	0·14	0·27	0·06
H_2O+	0·33	0·59	—
H_2O-	0·04	0·10	—
P_2O_5	—	tr.	0·07
CO_2	0·12	1·03	—
FeS_2	0·25	0·34	—
S	—	—	0·98
C	—	—	0·79
H(?)	—	—	0·25
Cl	—	—	tr.
Totals	100·72	99·89	100·72
Sp. gr.	3·11	3·04	2·958
Analyst	C. C. Williams.	E. S. Simpson.	

I. Fine-grained amphibolite. G.S.M. 3823, Cue. Bull. Geol. Surv. W. Austral. No. 29 (1907) pt. 2, p. 53.
II. Fine-grained amphibolite. G.S.M. 4425. Mount Malcolm, Mount Margaret Goldfield. *Ibid.* No. 11 (1903) p. 7.
III. Basalt. Ovifak, Disko (Greenland). H. Rosenbusch, 'Elemente der Gesteinslehre' 3rd ed. (1910) p. 399.

[1] Bull. Geol. Surv. W. Austral. No. 29 (1907) pt. 1, pp. 17–18; pt. 2, pp. 9, 44, 46, 52, & 53.

(c) The Fine-Grained Greenstones.

Generally speaking, these rocks are most abundant in the southern part of the 'North End,' passing gradually into the amphibolites on the north and into the calc-schists on the south, without being positively confined to this area. They are dark-green massive or slightly-schistose rocks when mined, but frequently develop a latent schistosity after exposure for some years in dumps. Microscopically they are exceedingly variable in appearance, but agree in consisting of fine-grained aggregates of carbonates, chlorite, sericite, quartz, and rutile, to which should probably be added untwinned felspars, although these have escaped identification. There is seldom any well-defined structure, except in some cases a tendency to parallel arrangement in the sericite and chlorite, or the development of large rhombohedra of carbonates. All gradations from the fine-grained amphibolites to perfectly structureless greenstones can be traced, and it may be observed that hornblende disappears before zoisite or epidote.

In the eastern part of the 'North End' are several occurrences of an apparently concretionary greenstone with small light-coloured ellipsoids distributed in a dark-green dense matrix. These whiter patches differ from the rest of the rock only in the greater abundance of calcite, with a corresponding diminution in the amount of chlorite. In all probability, these rocks are derived from contact-altered amphibolites similar to those of Monument Hill described above; and it is found, on careful mapping, that they are distributed around the margin of the great intrusion of peridotite that lies within the greenstones of the 'North End.'

Another type of greenstone showing abnormal characters may be described here, although its position among the older greenstones is not unequivocal. On the east side of Trafalgar Township, east of 'The Mile,' are several dumps containing a schistose rock in which small, black, lustrous crystals of chloritoid are plentifully developed along planes oblique to the schistosity. This mineral has sharper outlines and higher refringence than the chlorite also present in the rocks, possesses a well-marked pleochroism in blue-green to yellow-green tones, shows polysynthetic twinning with oblique extinctions up to 28° measured from the trace of the twin-plane, and has a high birefringence and strong dispersion. A blowpipe examination failed to give a reaction characteristic of manganese, so that ottrelite is excluded. The rocks consist chiefly of calcite, forming broad bands of coarse mosaic alternating with narrower bands of chlorite (pennine), and it is within or near the last-named that the chloritoid is developed. Rutile is very abundant in slender prismatic crystals showing knee-shaped and heart-shaped twins, and is freely enclosed by the chloritoid. A small amount of quartz and muscovite sometimes accompanies the calcite. The rocks are often brecciated and recemented by a matrix in which chloritoid and pyrite play a considerable part. Chloritoid is usually regarded as a mineral characteristic of contact-

or pressure-metamorphism, but Prof. E. Weinschenk has remarked that it is absent in contact-rocks containing calcite.[1] The presence of considerable amounts of chlorite and rutile shows that these rocks are not altered sediments, and suggests that they are formed from the greenstones; but their field-relationships are not sufficiently clear to give the clue to their probable mode of origin.

(*d*) The 'Calc-Schists.'

The name of 'calc-schists' was applied to these rocks by Dr. Maclaren before their true nature was ascertained, and has been adopted by Mr. Gibson. These rocks are more often massive than schistose, especially when freshly mined, and hence the name is not quite applicable; but it will be retained for convenience, since a distinctive name is necessary for the miner. The greatest development of the 'calc-schists' is on the eastern side of the quartz-dolerite boss of 'The Mile'; but they persist for some distance northwards, gradually merging into the fine-grained greenstones. In hand-specimens they are whitish-green aphanitic rocks, intersected by dark venules like those of chalcedony in serpentine; and, owing to close jointing, they possess a very short fracture. They are so dense that a high power of the microscope is required to distinguish the individual grains of the carbonate of which the rock is mainly composed, and to reveal the presence of quartz between them. In places, they contain small lath-shaped sericitic areas recalling those of the felspars in the fine-grained amphibolites. Chlorite is absent, or but sparingly present in large flakes. Occasionally, large octahedra of magnetite are scattered through the rock. In the more schistose varieties the muscovite exhibits some approach to parallelism, and large rhombohedra of carbonate are frequently developed.

(*e*) The Peridotites and their Derivatives.

In the hills forming the western shores of Hannan's Lake and the eastern slopes of Mount Hunt, 6 miles south of Boulder, a considerable area is occupied by a dense serpentine and a coarse carbonated serpentine. The former rock consists mainly of serpentine pseudomorphs after olivine-grains, embraced by a turbid mineral resembling bastite, and in addition a variable amount of tremolite, both as fine needles within the serpentine and as coarser prisms lying in the bastite. The original rock was probably, therefore, an augite or enstatite-peridotite. In the carbonated forms, the tremolite and bastite are little affected, but the serpentinous areas are almost completely replaced by a carbonate approximating to magnesite in composition.

Within the Kalgoorlie area proper, serpentine has been observed in only two places: Mr. Simpson[2] has recorded a rock 'of a serpentinous nature' from the former Black Cat lease, G.M.L. 3862 E;

[1] 'Grundzüge der Gesteinskunde' vol. i (1906) p. 139.
[2] 'Ann. Rep. Geol. Surv. W. Austral. for 1900 (1901) p. 9.

and a boring core from the neighbouring old Kaipai Mine, G.M.L. 3625 E, has also proved to be a serpentine essentially similar to that from Hannan's Lake, except that it contains more original chromite and secondary magnetite. Though no outcrop of this serpentine can be found, the rocks in this neighbourhood (the eastern part of the 'North End') are largely derivatives of peridotites, and may be classed as talc-magnesite rocks and schists, magnesite-rocks, and fuchsite-magnesite rocks. In most of them all trace of the original structure has been destroyed, but the mineralogical composition leaves no doubt as to their original ultrabasic and highly magnesian character. The talcose rocks consist mostly of a schistose matrix of talc with subordinate biotite, chlorite, and quartz, in which matrix large euhedral rhombohedra of magnesite are enclosed. In hand-specimens these rocks are unusually dark for talc-schists, and can be distinguished from the greenstone schists only by their soapy feel. The magnesite-rocks differ mineralogically from the carbonated serpentines of Hannan's Lake in the constant presence of talc and quartz, and structurally by the disappearance of recognizable pseudomorphs of olivine and pyroxene. The fuchsite-magnesite rocks are bright-green variants of the magnesite-rocks on the sides of small quartz or carbonate veins containing tourmaline, and consist of structureless aggregates of magnesite, quartz, fuchsite, and rutile.

Similar derivatives of peridotites attain a great development in the country east of Kalgoorlie, and particularly in the Bulong, Waterfall, and Kanowna goldfields. A belt of serpentine very similar to that of Hannan's Lake crosses the Bulong Road $6\frac{3}{4}$ miles east of Kalgoorlie, and shows clearly the pœcilitic structure of the tremolite-bastite element, as also the invasion of the serpentine by delicate needles of tremolite. A distinct feature is the growth of secondary magnetite within the bastite, in long arborescent crystals. In the dump of the Oversight Mine, Bulong, is a beautifully lustre-mottled rock, obviously derived from a serpentine. In natural light, thin sections of this rock resemble an ordinary serpentine, because of the retention of strings of iron-ores along the edges and cracks of the original olivine. A small amount of serpentine is occasionally retained in the centres of these original grains, but the exteriors are generally altered to talc. In parts of the rocks big crystals of carbonate replace the areas originally occupied by several olivine-grains, except for small patches of serpentine or talc in their centres which display in hand-specimens the dull patches of the lustre-mottling. Talc-carbonate rocks showing greater similarity to those of Kalgoorlie are found in the Golden Ridge Mine, Waterfall. At Kanowna is a hill of tremolite-serpentine north-west of the town, while fuchsite-magnesite rocks are very abundant near the gold-veins.

Outside the Kalgoorlie fields, serpentines have not been very frequently noticed in Western Australia; but this does not necessarily mean that they are uncommon. Little exploratory work has been carried out beyond the immediate neighbourhood of known gold-occurrences, and serpentine is not a rock in which auriferous

veins commonly occur, for the vein-solutions alter it to a talcose or carbonate-rock, and the talc-schists are frequently confused with the greenstones. Two serpentines from the West Pilbara Goldfield, which I described in 1909,[1] differ from those of the Kalgoorlie type in the absence of bastite and tremolite and in the presence of flakes of biotite or chlorite derived from it; and another Pilbara example (G.S.M. 5375, hills near Box Soak), previously noticed by Mr. E. S. Simpson,[2] is essentially similar. The serpentines described by the last-named writer and Mr. L. Glauert[3] from Ravensthorpe (G.S.M. 8154, 8326) appear to be dunite-serpentines showing incipient alteration to talc and carbonates. Talc-carbonate schists seem to be well developed at Warrawoona, while contact-altered tremolite-talc schists are found in fields of the Coolgardie type.

ANALYSES OF DERIVATIVES OF PERIDOTITE.

	IV.	V.	VI.	VII.	VIII.
SiO_2	39·35	31·07	33·80	38·91	30·63
TiO_2	0·60	0·26	0·33	0·06	0·52
ZrO_2	—	—	0·02	—	—
Al_2O_3	6·56	5·49	5·72	1·08	1·68
Cr_2O_3	—	—	0·50	—	—
U_2O_3	—	—	trace (0·005)	—	—
Fe_2O_3	—	1·49	0·40	10·30	5·94
FeO	9·45	7·64	8·70	1·80	4·72
MnO	1·57	0·18	0·19	0·08	0·11
MgO	28·51	17·49	19·95	36·65	32·30
CaO	3·10	5·46	1·34	tr.	tr.
BaO	—	—	none	—	—
Na_2O	0·73	3·82	0·30	0·40	0·41
K_2O	0·15	0·11	2·11	tr.	0·11
H_2O+	9·05	0·05	0·59	10·89	0·52
H_2O-	0·14	0·07	0·09	0·28	0·15
P_2O_5	—	—	0·11	—	—
CO_2	none	27·24	25·98	none	23·03
FeS_2	none	0·06	0·24	none	0·20
Totals	99·21	100·43	100·37	100·45	100·32
Sp. gr.	2·81	2·89	2·97	2·69	2·91
Analyst	C. C. Williams.	C. G. Gibson.	E. S. Simpson.	E. S. Simpson.	E. S. Simpson.

IV. Tremolite-serpentine. G.S.M. 3218. Near Hannan's Lake, Kalgoorlie. Bull. Geol. Surv. W. Austral. No. 6 (1902) p. 75.
V. Carbonated serpentine. G.S.M. 375. Island, western side of Hannan's Lake, Kalgoorlie. *Ibid.*
VI. Fuchsite-magnesite rock. Dump a quarter of a mile east of Hannan's North, G.S.M. 2139 E, Kalgoorlie. (Analysis hitherto unpublished.)
VII. Chlorite-serpentine. G.S.M. 5375. Hills near Box Soak, Pilbara Goldfield. Bull. Geol. Surv. W. Austral. No. 15 (1904) p. 12.
VIII. Talc-carbonate schist. G.S.M. 5757. Near Moolyella Gap, Warrawoona, Pilbara Goldfield. *Ibid.* No. 20 (1905) p. 66.

[1] Bull. Geol. Surv. W. Austral. No. 33, pp. 144 & 147.
[2] *Ibid.* No. 15 (1904) pp. 12 & 16.
[3] *Ibid.* No. 35 (1909) p. 39.

(*f*) The Hornblende-Rocks (Pyroxenite-Amphibolites).

These rocks appear only in a few dumps, both on the east and on the west side of the main dyke of quartz-dolerite, and are intimately associated with talc-schists and magnesite-rocks. The disposition of these dumps suggests that the rocks either form long, narrow, independent dykes in the peridotites, or that (with the latter) they form a banded complex.

In hand-specimens and thin sections alike they are found to consist almost entirely of large interlocking crystals of pale fibrous hornblende, without any trace of parallel structure, except in the immediate vicinity of local shear-planes. In places, the presence of brown hornblende of more massive character betokens a small amount of original hornblende. The brown hornblende shades off to green on its edges; generally it has outgrowths of massive tremolite, such as commonly occur on the original hornblende of uralitic and pilitic rocks. Iron-ores are rare, and are altered on the exterior into leucoxene or granular sphene. Still more rare are felspar (saussuritized), apatite, and biotite; while a small amount of interstitial micropegmatite has been observed in one specimen. As in all the amphibolites, surface-weathering has produced a variable amount of chlorite and epidote from the hornblendes.

The only rational explanation of the mode of origin of the dominant pale fibrous hornblende is that it is uralitic: therefore, the original rock must have been a pyroxenite containing a small amount of brown hornblende.

Pyroxenite-amphibolites, with or without original brown hornblende, have so far been found in only a few Western Australian goldfields, but are probably of wider distribution. G.S.M. 3963, from Lennonville, is, as Mr. Gibson[1] has already pointed out, a partly uralitized pyroxenite, and consists only of augite, pale fibrous hornblende, and granular sphene. G.S.M. 8322 (from Mount Desmond, Phillips River Goldfield), which Mr. Simpson & Mr. Glauert have compared with the Kalgoorlie type,[2] is a similar rock in which uralitization is complete. A more complete analogy with the Kalgoorlie type is shown by a rock from Lawlers (G.S.M. 7105), containing a small amount of brown hornblende in addition to the dominant uralite. A rock from Ravensthorpe (G.S.M. 8140), described by Mr. Simpson & Mr. Glauert[3] as an altered diabase, shows a much greater amount of brown hornblende, and in this respect constitutes a passage to the lustre-mottled amphibolites. The brown hornblende is almost opaque from the presence of inclusions of iron-ores, arranged for the most part in rows oblique

[1] Bull. Geol. Surv. W. Austral. No. 8 (1903) p. 13.
[2] *Ibid.* No. 35 (1909) pp. 26, 28.
[3] *Ibid.* pp. 27, 43.

to the vertical axis of the crystals (fig. 1). It is often crystallographically continuous with clear green or colourless hornblende; but the boundary-line is sharp, with no shading of colours as in the Kalgoorlie type. The bulk of the rock consists of clear, strongly-pleochroic, green hornblende in large and small crystals of more

Fig. 1.—*Hornblende-fels, G.S.M. 8140, Ravensthorpe, consisting of original brown hornblende (shaded, and with oblique rows of iron-ores), secondary green hornblende (clear), and sphene (dotted).* ×20.

compact character than is the case with the simply-uralitized amphibolites; and it is evident that the rock has attained a higher degree of metamorphism, most probably through contact-alteration.

No analyses of pyroxenite-amphibolites from Western Australia are available.

(*g*) The Lustre-Mottled Amphibolites (Hornblende-Dolerite-Amphibolites).

These rocks in Kalgoorlie do not form separate intrusions, but occur as local variations of the main band of quartz-dolerite-amphibolite at two or three points on its western side. They may easily be detected in hand-specimens by the lustre-mottling on the cleavage-surfaces of large hornblende-crystals, which range up to 15 mm. in their longest diameters.

Owing to the large dimensions of the hornblende-crystals, only a few of these appear in a thin section of average size. They are made up of variously coloured amphiboles, ranging from a deep brown through a vivid blue-green to pale-green and almost colourless varieties, the last two being in excess. The lustre-mottling is the outward expression of a pœcilitic structure—due in part to the enclosure of narrow prismatic masses of saussurite within the hornblende, and in part to the presence of ellipsoids of tremolite, surrounded by the coloured hornblende, but in crystallographic continuity with it. The saussurite-pseudomorphs are nearly opaque, and consist predominantly of clinozoisite and epidote, with relatively little albite; they still retain the crystal form of the original felspars very faithfully. Iron-ores are not abundant, and are altered to leucoxene or granular sphene. In chloritized specimens pyrite is also present.

The brown hornblende must certainly be regarded as original. Like that of the rocks described in the last section, it is often rendered nearly opaque by rows of ferruginous inclusions obliquely transverse to the cleavage-planes. In 1908, when studying the hornblende-peridotite and lustre-mottled amphibolite of Glendalough, I ascribed this structure to the magmatic resorption of augite [1]; but subsequent study of many similar rocks which exhibit it from Cornwall, Scotland, New Zealand, and Western Australia, has led me to the view that it is the result of an accommodation to increasing pressure according to the volume law. As it is known to develop only in the magmatically-formed brown hornblende of igneous rocks, it forms a valuable means of verifying the original nature of the brown hornblende of amphibolites; and, further, when the original hornblende shows this structure, the distinction of the secondary hornblende is rendered more certain.

The deeply coloured blue-green borders of the brown hornblende recall those so common in hornblende-peridotites, in which rocks they are usually explained as a bleaching of the brown variety; although, possibly, they arise by an interchange of material with the pilitic hornblende formed from the olivine. The bluish hornblende is not arfvedssonite, as supposed by Mr. Simpson.[2] It is to be distinguished from the blue-green hornblende of contact-altered amphibolites by its inconstant character, for it varies in colour gradually and irregularly from place to place; whereas in the latter the colour remains constant in any one crystal, or is suddenly replaced along a crystallographic plane by a different colour.

The pale and often fibrous hornblende occurring in the interstices of the larger crystals as outgrowths on the brown and green hornblende, or as patches within the latter, must be regarded as secondary, and of uralitic or (as suggested below) of partly pilitic origin.

[1] Q. J. G. S. vol. lxiv (1908) p. 481, figs. 2 & 7.
[2] Bull. Geol. Surv. W. Austral. No. 6 (1902) p. 64.

The original rock was, therefore, in all probability a pœcilitic hornblende-dolerite or gabbro. This view is confirmed by the study of a rock found by Dr. Maclaren 10 miles south-east of Kanowna. It is a hornblende-dolerite of the Careg-Llefain type, showing partial uralitization, and, where most altered, reproduces the features of the Kalgoorlie type.

The following is an analysis of a lustre-mottled amphibolite from Kalgoorlie, the only example of this class from Western Australia that has been analysed. The high percentages of carbon-dioxide, combined water, and soluble bases show that the rock had suffered much surface-decomposition, accompanied by the production of chlorite and carbonates.

	IX.	Bases soluble in *aqua regia*.
SiO_2	44·23	
TiO_2	0·06	
Al_2O_3	10·89	4·11
Fe_2O_3	0·13	0·13
FeO	14·22	5·00
MnO	1·60	1·13
MgO	11·42	3·15
CaO	10·43	0·59
Na_2O	1·02	
K_2O	0·20	
H_2O+	4·25	
H_2O-	0·22	
CO_2	1·29	
FeS_2	0·26	
Total	100·22	
Sp. gr.	3·00	
Analyst	C. G. Gibson.	

G.S.M. 2117. Main Shaft, Great Boulder, No. 2, South. G.M.L. 1219 E.
Bull. Geol. Surv. W. Austral. No. 6 (1902) p. 67

Lustre-mottled amphibolites have not been found abundantly so far in Western Australia; but one was described by me, in 1909, as almost a hornblende rock after a basic hornblende-olivine-gabbro.[1] The former presence of olivine was inferred from the presence of colourless ellipsoids of tremolite within the large pœcilitic crystals of brown hornblende, but this phenomenon could be equally well explained by the uralitization of enclosed augite. In the case of the Glendalough rocks previously mentioned, the olivine of the hornblende-peridotite is partly altered into chlorite and tremolite, and the last-named has grown inwards from the enclosing brown hornblende in parallel position upon it, while the chlorite has developed along cracks in the olivine. In the Glendalough amphibolite, where the olivine has completely disappeared, the abundance

[1] Bull. Geol. Surv. W. Austral. No. 33 (1909) pp. 132 & 142.

of colourless ellipsoids of tremolite within the brown hornblende corresponds rather to the former proportion of olivine in the rock than to that of augite; and this leads to the belief that such ellipsoids in lustre-mottled amphibolites may be, at least in part, the result of the replacement of olivine. Unless, however, there are remnants of olivine still retained in a rock, it is unsafe to postulate the former presence of the mineral, as microscopic criteria for distinguishing tremolite formed from pyroxene and from olivine respectively appear to be non-existent.

A priori, three types at least of lustre-mottled amphibolites may be distinguished :—

(1) Those formed from hornblende-peridotites; (2) those formed from hornblende-olivine-dolerites or gabbros; and (3) those formed from hornblende-dolerites or gabbros without olivine.

Of these types only the last-named has as yet been found in Western Australia. A fourth possible type might be formed from a pyroxenite containing much original hornblende, or an augite-hornblendite, if the augite occurred in pœcilitic crystals. The pyroxenite-amphibolite from Ravensthorpe described above approximates closely to this category, but the lustre-mottling is very local in character.

Lustre-mottling is not confined to igneous rocks containing pœcilitic hornblende, but is also found in some that contain pœcilitic augite. Amphibolites derived from such rocks would scarcely be expected to retain this character so clearly as those derived from hornblendic rocks, for the process of uralitization does not develop compact crystals, such as would give rise to smooth cleavage-surfaces like those found in residual brown hornblende.

(*h*) The Epidiorites.

These rocks are uralitized, saussuritized, and leucoxenized gabbros or ophitic dolerites, and are of a type so common that detailed descriptions are unnecessary. They have a very small development in Kalgoorlie, where they occur only as a local facies of the quartz-dolerite amphibolite, but are more abundant in the ridges to the west of the town; while an incompletely-uralitized dyke is found 3½ miles south of Bulong on the Mount Monger Road. No analysis of this type from Kalgoorlie has been made.

Epidiorites are of very common occurrence among the amphibolites of Western Australia, and their derivation from 'diabase' has in some cases been recognized by Dr. Vogelsang, Mr. Simpson, and Mr. Gibson. In 1909 I described several in detail from the Northern Goldfields, including pegmatitic varieties (G.S.M. 6401, 6410, 6414, 6434, 6437, 6442).[1] The following analyses (p. 643) refer to rocks of this class.

[1] Bull. Geol. Surv. W. Austral. No. 33 (1909) pp. 135–36, 138, 140, 146, 147, & 150; also figs. 45 & 46.

ANALYSES OF WESTERN AUSTRALIAN EPIDIORITES.

	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
SiO_2	46·27	46·44	46·55	48·09	49·94	50·98	50·98
TiO_2	0·49	0·42	1·12	0·12	0·52	0·70	0·79
Al_2O_3	23·85	20·22	15·36	19·77	19·45	11·06	17·09
Fe_2O_3	1·36	1·91	3·19	1·43	—	5·72	0·87
FeO	3·51	3·99	8·79	6·99	7·21	10·67	8·35
MnO	0·32	0·22	0·45	0·29	0·63	0·65	1·25
MgO	6·65	9·19	9·80	7·56	9·64	5·88	4·70
CaO	14·89	15·18	10·56	11·30	11·23	8·09	9·70
Na_2O	1·52	1·05	1·50	2·17	0·90	2·75	4·09
K_2O	0·13	0·10	0·33	0·07	0·07	2·11	0·10
H_2O+ ...	1·17	0·06	1·31	2·05	0·73	1·73	1·08
H_2O- ...	0·11	0.18	0·29	0·17	0·06	0·28	0·05
P_2O_5	0·11	0·36	0·06	—	—	—	—
CO_2.........	0·25	0·24	tr.	0·12	—	none	none
FeS_2	0·08	0·20	tr.	0·11	0·05	0·44	0·19
Totals...	100·71	99·76	99·31	100·24	100·43	101·06	99·24
Sp. gr. ...	2·90	3·03	3·04	2·98	2·94	2·94	2·95
Analyst.	J.H.B.	J.H.B.	E. S. Simpson.	(?) C. C. Williams.	E. S. Simpson.	C. G. Gibson.	C. C. Williams.

X. G.S.M. 6874. Homeward Bound G.M., Cue. Bull. Geol. Surv. W. Austral. No. 29 (1907) pt. 2, p. 53.
XI. G.S.M. 6870. Polar Star G.M., Cue. *Ibid.*
XII. G.S.M. 4417. Yarri, North Coolgardie Goldfield. *Ibid.* No. 11 (1903) p. 7.
XIII. G.S.M. 3847. Water Reserve 7745, Cue. *Ibid.* No. 14 (1904) p. 15; and No. 29 (1907) pt. 2, p. 53.
XIV. G.S.M. 5999. Sunbeam G.M.L. 157, Norseman. *Ibid.* No. 21 (1906) p. 119.
XV. G.S.M. 3751. Camp F.B. 32, Charnley River, Kimberley. Analysis hitherto unpublished.
XVI. G.S.M. 5088. Tower Hill G.M.L. 4387, Leonora. *Op. cit.* No. 13 (1904) p. 19.

(*i*) Derivatives of Quartz-Dolerite.

The rock here named quartz-dolerite was originally a coarse-grained intrusive rock, such as that of Carrock Fell, termed by Mr. Harker a 'quartz-gabbro' and by Prof. Rosenbusch a 'quarzdiabas.' The original presence of such a rock in Kalgoorlie is demonstrated most clearly by the study of epidiorites with micropegmatite, but might be directly inferred also from some of the greenstones in which the original structural relations are not entirely obliterated. From these clear types one is led on by gradations to rocks of a very nondescript character, the parentage of which would be doubtful if they were found isolated. All the various kinds of derivatives, when taken together, are found to form a broad band traversing the entire field in a north-north-westerly and south-south-easterly direction, and swelling out into a roughly boss-shaped mass in 'The Mile.' The boundaries of this mass are determined by a complex system of faults, but the northern and southern bands have the appearance of a dyke *in situ.* From the eastern side of the boss other thinner dykes run for some distance north and south.

It will be convenient, in description, to group the rocks under three main types.

A. Epidiorites with Micropegmatite (Quartz-Dolerite-Amphibolites).

The amphibolitic variety forms a fairly-persistent band of varying width on the west side of the main dyke, and in parts of the 'North End' extends right across the outcrop. The rocks are, in general, not so deeply oxidized as the chloritic varieties, and may be collected at the surface in many places, notably near the Warden's House and in the eastern railway-cutting through the Hannan's Proprietary Lease (4222 E). South of 'The Mile' there is also a good exposure in a quarry in the old Leviathan Boulder Lease (1072 E).

In hand-specimens the rocks are mostly coarse-grained and of a greenish-grey colour. The bright cleavage-surfaces of dark-green hornblende are conspicuous, and appear to be scattered about in a dull-white saussuritic material. In general, it is impossible to recognize the presence of quartz without the help of a lens, nor is leucoxene so conspicuous as in the greenstones. The rocks at the southern end of the field have a darker green coloration, due to the prevalence of epidote, and are traversed by venules of quartz and epidote.

Despite the alterations that have taken place, the structural relations between the minerals of the original rock are very completely preserved. Saussuritic pseudomorphs of earlier columnar plagioclase are embraced ophitically by leucoxene and by uralitic pseudomorphs of pyroxene. In the interstices of the framework thus constituted a variable amount of micropegmatite or quartz occurs. The earlier felspars have rarely escaped complete saussuritization, and are generally replaced by almost opaque aggregates of zoisite, or more rarely of brownish-green epidote. The previously-existing pyroxenes are completely altered in the Kalgoorlie area to an almost colourless, markedly-fibrous uralite, which projects in a ragged fringe into the quartz-felspar intergrowths. Apparently, also, original hornblende was present: for there is a small amount of bright-green, pleochroic, compact hornblende on the outer borders of the uralite, and in crystallographic continuity with it. The marked contrast between the two varieties of amphibole must arise from some difference in mode of origin, and the simplest explanation is that the one is original and the other secondary. The iron-ores are occasionally preserved without alteration, but more often are represented by leucoxene and occasionally by granular sphene. The interstitial quartz and felspar often form micrographic intergrowths, but these are seldom so well-defined as those seen in the greenstones. The later felspar is obscured by inclusions of zoisite and sericite, but in places is fresh enough to allow the species to be recognized as an intermediate plagioclase. Both the micropegmatite and the interstitial quartz are rich in inclusions of apatite.

The analysis of a Kalgoorlie rock of this type (tabulated on p. 645) is very similar to those of fresh quartz-dolerites from Great Britain.

The presence of micropegmatite in the amphibolites of Western Australia was first pointed out by Dr. Vogelsang[1] in a rock from the Murchison district in 1897, but the inference that the rock was a derivative of a quartz-dolerite or a quartz-gabbro was not definitely drawn. Similar rocks are of very common occurrence in the Western Australian goldfields, but have generally been classed by the Survey officers as quartz-diorites, despite their basic nature. In 1909 I described several in detail as uralitized and saussuritized quartz-dolerites and quartz-hornblende-dolerites[2] (G.S.M. 6407, 6432, 6443, 6483, & 6484).

ANALYSES OF QUARTZ-DOLERITES AND QUARTZ-DOLERITE-AMPHIBOLITES FROM WESTERN AUSTRALIA.

	XVII.	XVIII.	XIX.	XX.	XXI.
SiO_2	48·86	49·42	52·70	52·31	51·93
TiO_2	0·22	1·95	0·83	0·41	1·75
Al_2O_3	14·91	14·95	14·27	14·64	14·26
Fe_2O_3	—	1·38	1·48	3·09	2·49
FeO	11·13	10·76	11·07	5·87	10·76
MnO	0·90	0·47	0·18	0·29	0·57
MgO	7·65	6·16	6·39	8·90	5·28
CaO	12·19	9·85	8·23	9·32	7·89
Na_2O	2·58	2·70	3·15	2·57	2·79
K_2O	0·19	0·72	0·23	0·59	0·81
H_2O+	1·51	0·77	0·12	0·88	1·13
H_2O-	0·04	0·09	0·24	0·25	0·09
P_2O_5	—	0·55	—	0·31	0·31
CO_2	none	none	0·15	0·05	none
FeS_2	—	0·26	0·49	0·02	0·15
Totals	100·18	100·03	99·53	99·50	100·21
Sp. gr.	3·08	3·01	2·96	3·00	3·00
Analyst	C. C. Williams.	E. S. Simpson.	(?) C. G. Gibson.	E. S. Simpson.	E. S. Simpson.

XVII. Quartz-dolerite-amphibolite. G.S.M. 3231, Star of Colac G.M.L. 2872 E., Kalgoorlie. Bull. Geol. Surv. W. Austral. No. 6 (1902) p. 67.

XVIII. Fresh quartz-dolerite. G.S.M. 7728, Irregully Creek, Ashburton Goldfield. *Ibid.* No. 33 (1909) p. 164.

XIX. Quartz-dolerite-amphibolite. G.S.M. 5631, G.M.L. 375, near Greenmount G.M., Southern Cross. *Ibid.* No. 17 (1904) p. 20.

XX. Quartz-dolerite-amphibolite. G.S.M. 6858, Red, White, & Blue G.M.L. 745, Cue. *Ibid.* No. 29, pt. 2 (1907) p. 53.

XXI. Fresh quartz-dolerite. G.S.M. 7616, Secret Creek, Ashburton River. *Ibid.* No. 33 (1909) p. 164.

Pegmatitic Varieties of Quartz-Dolerite-Amphibolites.

These rocks are found in Kalgoorlie at various places along the main band of quartz-dolerite-amphibolite, particularly on the west

[1] In K. Schmeisser, 'Die Goldfelder Australasiens' Berlin, 1897, p. 44. English translation by H. Louis, London, 1898, p. 63.

[2] Bull. Geol. Surv. W. Austral. No. 33 (1909) pp. 136–37, 144–45, 150–51, & 155–56; also figs. 52 & 54.

side of Mount Gledden (Maritana Hill) and in the dump of the Queen-of-the-West Mine, G.M.L. 942 E. Although no natural sections have been observed *in situ*, large blocks in the dumps show that the pegmatitic rocks occur as narrow bands in the normal amphibolite. The rock from which they have arisen thus bears the same relation to the main intrusion, as the well-known gabbro-pegmatites of the Lizard district in Cornwall bear to the gabbros of that area.

Hand-specimens show a very coarse mottled rock, of a prevailing dark-green hue, with white patches representing the felspar and quartz. The most noticeable peculiarities are the platy habit of the femic constituent, and the manner in which these plates are bent into curves with arcs approaching a semicircle, so that a broken surface of the rock seems to have small biscuit-barrels projecting from it. On a typical fragment, less curved than usual, one of these platy crystals measured 4 cms. in length, 1 cm. in breadth, and 2 mm. in thickness. A transverse striation is often to be observed in hand-specimens, although nothing corresponding to it has been detected in section. The quartz-and-felspar or saussuritic aggregates are generally of much smaller size; but the iron-ores, which have also a platy habit, attain 5 cms. in their greatest diameters. Veins of yellowish epidote and quartz sometimes traverse the rocks.

Microscopic study shows that the dark plates consist of a pale-green hornblende, and that the rocks are built on the same model as the normal quartz-dolerite-amphibolites, but on a much grander scale. The chief points of difference are that the pyroxene is represented largely by carbonates, chlorite, epidote, and magnetite, in addition to hornblende, and that the structure is not always clearly ophitic (for the platy felspars are sometimes moulded on the pseudomorphs of the pyroxenes). So far as I am aware, such pegmatites have not been described before, either in a fresh or in an altered state.

B. The Quartz-Dolerite-Greenstones (Albitized Quartz-Dolerites).

These rocks, along with those described in the next section, have a relatively-small development in the 'North End,' but occupy the greater part of the quartz-dolerite intrusion in the 'Mile.' They are not mere surface-weathering forms of the amphibolites, but exist at depths of 2500 feet and over. Owing to the variety and extent of the alterations that they have undergone, they present little appearance of homogeneity, and the recognition of their original nature is not (at first sight) easy. The rocks here termed 'greenstones' are more or less dark green from the abundance of chlorite; but every variation of colour is found between these and white or flesh-coloured rocks, in which chlorite is practically absent. The latter rocks are described in the next section as bleached greenstones, but it must be clearly understood that the boundary-line between the two divisions is an arbitrary one. In both groups there is every gradation between coarse granitoid varieties, approaching in texture the pegmatitic amphibolites above

described, and dense rocks hardly to be distinguished from the older fine-grained greenstones. Both groups, again, occur in perfectly massive and perfectly schistose forms; but the green chlorite-schists are quite subordinate in amount to the pale quartz-sericite-carbonate schists.

A constant characteristic in all but the most schistose members is the presence of dull yellowish to purple patches of leucoxene, which are most clearly evident on wetted surfaces. Even where there is a considerable development of magnetite or pyrite, part, at least, of the leucoxene is commonly retained. In some of the massive greenstones the outlines of the felspars are visible in hand-specimens, and their prismatic forms have led more than one observer to describe them as phenocrysts.[1] This deceptive appearance is due to the absence of distinct pseudomorphs of the original ferromagnesian minerals, which have altered to irregular masses of chlorite and carbonates and may easily be confused with the altered ground-mass of a porphyritic rock. Black blebs of quartz are abundant in the coarser rocks, the black being due merely to the background of chlorite in which the quartz is set.

The most strongly chloritic rocks are found in the 'North End' and on the western margin of 'The Mile': that is, in the proximity of the amphibolites. In section, the distinctive elements of the quartz-dolerites can clearly be recognized. The felspars are often well preserved as to form, although much coloured and obscured by chlorite along the cracks and cleavage-planes. They form large tabular crystals, often twinned on the albite law, less often on the pericline, and occasionally on rarer laws; but Carlsbad twins are seldom, if ever, seen. Their identification as albite rests on the following observations:—maximum extinctions on symmetrically-cut albite-twin lamellæ of 16°, refringence lower than that of balsam, maximum birefringence always low, optical character positive. On the felspars are moulded highly-embayed crystals of ilmenite, more or less altered to leucoxene. At times, there is in addition a considerable amount of octahedral magnetite, which in some cases encloses the ilmenite or leucoxene. A former mineral, which embraced the felspars ophitically, is represented by aggregates consisting principally of chlorite, with smaller amounts of carbonates and in a few cases of epidote. These aggregates are assumed to be the alteration-products of the original augite of quartz-dolerites, but there is no intrinsic evidence to prove that such is the case. The interstices between the above-described minerals (or mineral aggregates) are occupied by coarse or fine micropegmatite, the felspar of which is often polysynthetically twinned and may sometimes be seen to be continuous with that of the large columnar crystals. Apatite occurs as inclusions in all the above minerals, but is most abundant by far in the micropegmatite as long slender needles. Tourmaline is a rare accessory.

In rocks such as those described above, where the original

[1] As previously stated, Prof. Judd and Mr. Larcombe have termed these rocks 'quartz-andesites.'

outlines of the felspars are retained, and the alteration-products of the presumed pyroxenes still form distinct pseudomorphs, the structural analogy with quartz-dolerites is complete. It follows that the alteration, as compared with the original rock, consists in albitization of the felspars, and in conversion of the ilmenite into leucoxene and of the pyroxene mainly into chlorite and carbonates. The question arises whether this alteration has been effected directly on the fresh quartz-dolerite, or after it had been first uralitized. This will be discussed in the concluding part of this paper.

The greenstones of 'The Mile' seldom contain so much chlorite as the above-described rocks; and, by a breaking-down of the sharpness of the pseudomorphs it is not always easy, and sometimes impossible, to distinguish the distinctive elements and structure of the quartz-dolerites. The felspars are seldom entirely destroyed, but have lost their rectilinear outlines, and what remains is much obscured by inclusions of chlorite, carbonates, and sericite. The felspars of the micropegmatite have often completely disappeared. Consequently, it is no longer possible to isolate by exclusion certain aggregates of chlorite and carbonate as pseudomorphs of ophitic pyroxenes; and the rocks are, to all appearance, structureless aggregates of chlorite, carbonates, felspar, quartz, sericite, leucoxene, and apatite. Nevertheless, there are certain relict-structures of wonderful persistence, even under extreme alteration and after considerable shearing. Leucoxene is never completely absent, even in rocks in which much secondary magnetite or pyrite is present, and it preserves the large deeply-embayed forms which characterize ophitic ilmenite. Again, groups of quartz-grains extinguishing together, but widely separated by a structureless aggregate of chlorite and carbonates, are found in the most altered rocks. Mr. Card,[1] who supposed that these represented fragments of still larger quartz-crystals undergoing replacement, aptly compared them to islets of an archipelago (fig. 2, p. 649). The common crystallographic orientation of each 'archipelago,' and the abundance of apatite in the 'islets' and the intervening 'sea,' combined with the presence of micropegmatite in the less altered rocks, seem conclusive evidence that the quartz once formed part of a micrographic intergrowth. Not only has replacement caused the felspars to disappear, but it appears also to have obliterated the finer particles of quartz, and to have encroached on the larger. While it may be admitted that such archipelagos of quartz might arise in the manner suggested by Mr. Card from the quartz of a granite, their conjunction with leucoxene leaves no possible parent but an intrusive basic rock containing quartz.

As a secondary structure in these greenstones may be noted the occasional development of the carbonates into large euhedral rhombohedra—cutting indifferently across the junctions of the former minerals, and enclosing quartz, leucoxene, and muscovite. Often the composition of the carbonates varies from place to place

[1] Rec. Geol. Surv. N. S. W. vol. vi, pt. 1 (1898) p. 23.

in the same crystal, as if it were affected by the character of the minerals undergoing replacement. A similar development of large magnetite octahedra frequently accompanies the formation of the carbonate rhombs, but is also noticed in rocks in which the carbonates are not thus individualized. As both these minerals occur in sharp and uncrushed crystals in highly-sheared rocks, their formation appears to be posterior to the shearing.

Schistosity in the greenstones is most pronounced in the vicinity of the Golden Gate railway-station (at the north-western corner of

Fig. 2.—'*Archipelago' of quartz in quartz-dolerite-greenstone, Ivanhoe G.M.* × 30.

[The quartz is in the position of extinction. The rest of the field (not filled in) is occupied by a mixture of secondary minerals.]

'The Mile'), where every gradation between a slightly-sheared greenstone and a highly-fissile chlorite-schist may be observed. In the intermediate types 'augen,' formed of archipelagos of quartz and slightly-deformed leucoxene-crystals, are wrapped round by parallel layers of chlorite and muscovite, interspersed with bands of granular quartz. In the most schistose types the leucoxene is drawn out into long lenticular streaks, and has been largely replaced by rutile; the larger 'augen' of quartz have broken down, and parallel layers of chlorite and subsidiary muscovite alternate with layers consisting of a fine-grained mosaic of quartz, felspars, and carbonates.

There are many abnormal types of quartz-dolerite-greenstone, both in the 'North End' and in 'The Mile'; but, as their

significance is doubtful, and as they are geologically unimportant, it will serve no useful purpose to describe them in detail here. Mention should, however, be made of one specimen which might be considered the result of contact-metamorphism, as it occurs in the vicinity of a dyke of albite-porphyry. It was collected in the western cross-cut off the west drive, at the 300-foot level of the Hannan's Star Consolidated G.M. The rock has a dull-grey coloration seldom seen in any other variant of the quartz-dolerites; but, in section, it differs from the ordinary greenstones only in the substitution of chloritoid for chlorite in the pseudomorphs after the original pyroxene. Occasionally, the chloritoid projects into the sericitized felspars. Except in the occurrence of chloritoid, there are no characteristics suggesting contact-alteration, and greenstones from the contact of the albite-porphyry at other localities do not contain chloritoid,

Analyses of the greenstones will be found at the end of the next section (p. 652).

C. Bleached Greenstones (Albitized Quartz-Dolerites without Chlorite).

These rocks, as mentioned above (p. 646), pass gradually into the greenstones, and the distinction made is only for purposes of description. They occur chiefly in 'The Mile,' and, without forming exclusively the walls of the telluride-lodes or the matrix of the ores themselves, they are most abundant in what may be termed the lode-channels.[1] Sometimes, particularly in the 'North End,' the bleached greenstones are found as thin variants of the greenstones on each side of venules of quartz or albite. At other times, especially in parts of 'The Mile,' they form wide bands of rock alternating with similar bands of greenstone, the boundary between the two being sharp and usually along a strong joint-plane. This mode of occurrence has been supposed to indicate a later intrusive origin for the rocks under discussion, particularly where they have been identified as granophyres. It is probably due to movements along the joint-planes faulting out of sight those spots where the gradation between the two rocks occurs. Such gradations can be observed in innumerable cases, if very close inspection be made. Mine-workings are nearly always smothered with dust or slime, the lighting underground is poor at the best, and, in consequence, much hammer-work and close inspection is necessary before the true relationship of two adjacent rocks can be made out. Sudden breaks are much more easily noticed than

[1] The lodes of 'The Mile' may be divided, on geographical grounds, into three groups. The western group contains the lodes of the Ivanhoe, Great Boulder, and Golden Horseshoe Mines; the central group includes those of the Kalgurli, South Kalgurli, Great Boulder, Perseverance, and Lake-View Consols Mines; and the eastern the lodes of the Oroya-Brownhill, Associated Northern, and Associated Mines. Within each group the lodes are close together, and run in a belt of sheared and mineralized country that may be termed a lode-channel. The three groups are separated by broader belts of barren greenstone. The lodes of the western and central groups are in the quartz-dolerites, those of the eastern group in the calc-schists.

gradual passages. Here it may be observed that, although there is always an inherent probability of finding granophyres in association with quartz-dolerites, I have failed absolutely to discover any trace of them in Kalgoorlie, every suspected rock proving on microscopic study to be a metasomatized quartz-dolerite.

In hand-specimens the coarser rocks are white or various shades of pink, and present much outward similarity to granites; but they always reveal their doleritic origin by the presence of leucoxene. Microscopically they exhibit in many cases their original structure much better than the greenstones, for the absence or paucity of chlorite (an obscuring element in the greenstones) makes the distinction between the various pseudomorphs much sharper. The pyroxenes are represented by dense aggregates of carbonate grains disposed around the partly- or completely-sericitized felspars. Micrographic and micropegmatitic intergrowths of quartz and albite are often beautifully displayed, and in such abundance as to make it evident that the rocks thus altered were slightly more siliceous than those parts of the same intrusion that are now represented by amphibolites. The felspars, wherever identifiable, are albite, as in the greenstones. The leucoxene is frequently replaced by rutile, a process that becomes more marked with advancing schistosity.

As in the case of the greenstones, however, many of the rocks are not such obvious derivatives of quartz-dolerites, owing to a greater development of carbonates and sericite. They consist apparently of coarse-grained structureless aggregates of secondary minerals (chiefly quartz, carbonates, and sericite), but there are few in which the presence of leucoxene or of archipelagos of quartz does not betray the original character. Most of them contain a large amount of pyrite, the iron of which appears to have been furnished largely by the chlorite, for a disappearance of chlorite goes hand in hand with the appearance of pyrite.[1] Secondary magnetite is fairly common, while hæmatite and arsenopyrite are occasionally found.

In the immediate vicinity of the lodes these rocks are represented by pale-grey schists with silvery foliation-planes, often rough by reason of imperfect shearing or from the projection of octahedra of magnetite. In microscope-sections the schistosity is less evident than the hand-specimens would suggest. Sericite is the first mineral to assume a parallel development, and next to it comes chlorite (if any exists in the rock), then the carbonates, which are drawn out into lenticular streaks. The large magnetite-crystals seem to be posterior to the shearing: for their edges are quite sharp, and they are never flattened or drawn out. The ultimate products of the shearing are fine-grained schists with a granular quartz base, in which certain bands are very rich in rutile. These quartz-carbonate-sericite schists are the rocks regarding which Mr. L. J. Spencer[2] expressed doubts concerning their relationship with

[1] The alumina of the chlorite is probably utilized in the formation of sericite, while the magnesia is removed or goes into the carbonate.

[2] See p. 629.

the amphibolites. Great as are the mineralogical and chemical differences, there can be no doubt that both are derivatives of quartz-dolerites.

The following analyses (selected from a large series published by Mr. Simpson) illustrate the somewhat variable chemical composition of the greenstones and the bleached greenstones. An analysis of an albitized quartz-dolerite from Scotland is appended for comparison :—

Analyses of Quartz-Dolerite-Greenstones & Bleached Greenstones.

	XXII.	XXIII.	XXIV.	XXV.	XXVI.	XXVII.
SiO_2	57·72	55·84	45·55	46·94	42·01	59·33
TiO_2	1·13	0·62	0·63	0·14	0·81	3·42
Al_2O_3	9·68	10·38	10·88	12·49	8·42	12·86
Fe_2O_3	6·49	4·39	4·14	0·33	2·45	1·88
FeO	9·17	12·82	13·18	9·20	15·76	6·46
MnO	0·09	0·38	tr.	0·32	0·41	0·14
MgO	1·63	0·54	2·31	3·56	1·67	2·09
CaO	5·05	4·18	7·52	6·43	7·07	3·74
Na_2O	3·92	3·40	3·04	1·84	2·62	5·13
K_2O	0·12	0·76	0·26	2·57	1·15	2·15
H_2O+	1·51	1·83	1·74	0·30	0·67	2·12*
H_2O-	0·16	0·05	0·27	0·09	0·23	0·48
P_2O_5	—	—	—	—	—	0·388
CO_2	1·84	4·92	10·26	13·41	15·65	—*
F	—	—	—	—	—	0·044
FeS_2	—	0·22	0·34	2·25	0·30	0·215
Totals	98·51	100·33	100·12	99.87	99·22	100·44
Bases soluble in *aqua regia* :—						
Al_2O_3	4·46	3·50	0·78	0·31	0·20	—
Fe_2O_3	6·49	4·39	4·14	0·33	2·45	—
FeO	8·42	11·79	10·50	8·49	14·37	—
MnO	0·09	0·33	tr.	0·32	0·41	—
MgO	1·63	0·54	2·08	3·56	1·67	—
CaO	3·34	3·98	7·28	6·33	5·74	—
Sp. gr.	3·04	2·90	2·91	2·94	3·00	—
Analyst	C. C. Williams.	C. G. Gibson.	E. S. Simpson.	C. G. Gibson.	C. G. Gibson.	J. D. Falconer.

* H_2O+ and CO_2=2·12.

XXII. Epidotic greenstone. G.S.M. 1936, Hannan's North G.M.L. 673 E. Main shaft, 600 feet. Bull. Geol. Surv. W. Austral. No. 6 (1902) p. 67,

XXIII. Greenstone. G.S.M. 1800, western crosscut, 300 feet, Golden Horseshoe G.M.L. 993 E. *Ibid.*

XXIV. Greenstone. G.S.M. 1730, main shaft, Imperial Boulder, G.M.L. 1222 E. *Ibid.* ['Chlorite-schist.']

XXV. Bleached greenstone. G.S.M. 1753, 400-foot level, Ivanhoe G.M.L. 116, Boulder. *Ibid.* ['Lode stuff: chlorite-schist.']

XXVI. Bleached greenstone. G.S.M. 1751, western crosscut, 400 feet, Ivanhoe G.M.L. 116. *Ibid.* ['Massive siderite-rock.']

XXVII. Light-coloured felspathic modification of quartz-diabase. Kettlestoun Quarry, Scotland. J. D. Falconer, Trans. Roy. Soc. Edin. vol. xlv, pt. 1 (1906) p. 147.

The practice adopted by the chemists of the Western Australian Geological Survey of giving, in addition to the complete analysis, a statement of the part of the rock that is soluble in *aqua regia*, is highly commendable in the case of rocks containing much chlorite and carbonates: for thus it is possible to make an approximate estimate of the quantitative mineralogical composition. In these calculations one method is to employ arbitrary molecules for chlorite and sericite; and this has been adopted by Dr. W. Lindgren[1] for the calculation of two of the analyses of the foregoing table. An alternative method, adopted by me, assumes an arbitrary choice of disposal of the soluble bases between carbonates and chlorite, and attempts to calculate the various molecules postulated by Tschermak for chlorite and sericite according to the ratios between combined water and the available bases. The latter method would be more exact if the analyses were absolutely reliable; but, in the absence of estimates of fluorine and chlorine, the figures given for combined water cannot be accepted as quite accurate. Nevertheless, it is interesting to note the close agreement of the calculations, particularly as it is evident from the slight divergences in the fixed molecules that slightly different atomic weights have been used. The estimates for the rocks in the foregoing table are as follows (XXV *a* and XXVI *a* being the estimates of Lindgren):—

	XXII.	XXIII.	XXV.	XXV *a*.	XXVI.	XXVI *a*.
Leucoxene	—	1·51	0·34	—	1·98	—
Ilmenite	2·14	—	—	—	—	—
Magnetite	7·45	6·36	0·48	0·47	3·55	3·53
Pyrite	—	0·22	2·25	2·25	0·34	0·30
Albite	33·12	28·72	15·56	15·70	22·16	22·12
Anorthite	—	0·97	0·50	—	0·44	—
Zoisite	8·43	—	—	—	—	—
Iron-epidote	3·06	—	—	—	—	—
Sericite	1·04	6·45	21·73	21·52	9·71	9·58
Chlorite	13·82	16·39	2·85	2·76	1·24	2·94
Carbonates	4·18	11·94	31·35	31·48	38·27	38·24
Quartz	25·26	27·85	25·13	25·20	21·23	21·44
Totals	98·50	100·41	100·19	99·38	98·92	98·15

No. XXIV could not be thus calculated, as the analysis shows much insoluble iron and alumina that cannot be accounted for. While it is frankly admitted that the results can only be accepted as approximate, the above table reveals several interesting points. The first is the thorough nature of the albitization, for little or no insoluble lime remains in any of the rocks, except the epidotic greenstones. The second is that, as the amount of sericite and carbonates increases, the proportions of albite and chlorite decrease. Apparently, after the production of the greenstones by albitizing solutions, in which process chlorite was freely formed, a further

[1] 'Metasomatic Processes in the Gold Deposits of Western Australia' Econ. Geol. vol. i (1906) p. 538.

alteration by later solutions took place, leading to more extensive formation of sericite and carbonates at the expense of the albite and chlorite. The term 'bleached greenstone' has been applied, not only because it avoids the necessity of some such phrase as 'metasomatized quartz-dolerite without chlorite'; but also because I believe that the rocks thus named have actually passed through the greenstone stage, and have been dechloritized. The amount of free quartz is much greater than is to be expected in a fresh quartz-dolerite; but it may probably be explained by the liberation of secondary quartz during the alterations sketched out above, without any extensive addition of silica to the rocks.

Lode-Matter in the Quartz-Dolerites.

The term 'lode' or 'lode-formation' is used in Western Australia for a body of ore which is not clearly a quartz-vein or reef, and has the general appearance of a rock rather than of a fissure-filling. It is generally agreed that the 'lode-formations' are zones of rock that have been strongly fissured or sheared, and impregnated or replaced in part by valuable minerals.[1] The only criterion of whether a given piece of rock is ore or country is the economic one of whether it will be profitable to mine or not. Such lodes are found in several kinds of rocks in Kalgoorlie; but those in the quartz-dolerite are the richest, and alone carry persistent shoots of ore.

Most of the bleached greenstones bear some percentage of pyrite, and are never without at least a low tenour in gold; whereas the greenstones are predominantly barren. The greater part of the actual ore mined consists of bleached greenstone-schists or much-silicified replacements of them; nevertheless, some of the high-grade telluride-ores are almost perfectly-massive greenstones or bleached greenstones such as have been described above. Detailed descriptions of the various kinds of ores would occupy too much space in a paper that is already of great length.

(*j*) The Porphyrites.

The rocks here classed together present considerable variety when compared one with the other, and range from grey rocks of dioritic facies to light-coloured, eminently porphyritic types, hardly distinguishable from the albite-porphyries. The porphyries and porphyrites differ from all the other rocks of the field in containing phenocrysts of felspar, and are thus easily recognized. The distinction drawn between them rests chiefly on the presence of hornblende and biotite in the porphyrites, and on the absence of these minerals in the porphyries. As a rule, too, the porphyrites consist more preponderatingly of phenocrysts, with a consequent diminution in the amount of the groundmass, and thus approach more nearly to plutonic rocks.

[1] See H. P. Woodward, 'The so-called "Lode-Formations" of Hannan's, & Telluride Deposits' Mining Journ. vol. lxvii (1897) pp. 1369–70.

While the porphyries range as dykes through the quartz-dolerites, 'calc-schists,' and peridotites of the Kalgoorlie ridge, the porphyrites are found chiefly in old dumps of abandoned mines and water-shafts in the valley west of 'The Mile' on which Boulder is built, and consequently it is not clear through what rocks they are intrusive. The distribution of these dumps, and of some outcrops on the rising ground, favours the view that there is a broad band of porphyrite with a trend similar to that of the other intrusives; but, if so, it is a composite intrusion, for the nature of the rocks varies in nearly every dump. In the hills composed of epidiorites and quartz-dolerite-amphibolites west of the Kalgoorlie-Boulder valley, there are various small dykes of porphyrite; and Dr. Maclaren has observed them as far to the south-east as Mount Monger.

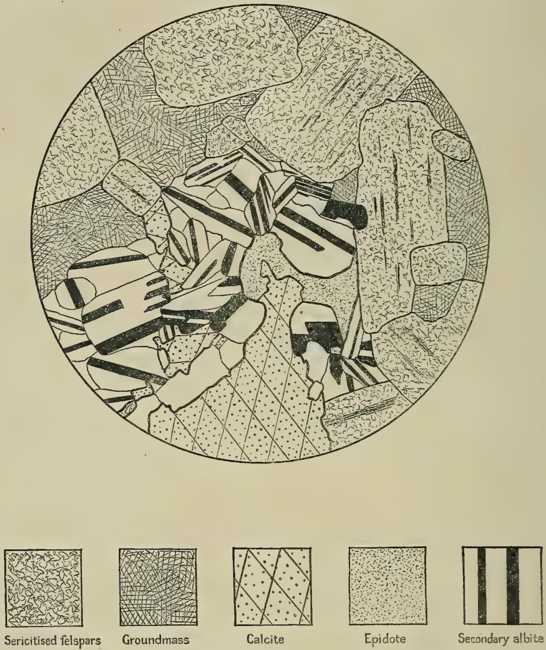
The differences within the group lie partly in the varying proportions of phenocrysts and groundmass, and partly in the relative proportions of felspar, hornblende, and biotite. The rocks which agree most closely with typical porphyrites show small phenocrysts of black hornblende and white felspar in a white or yellow felsitic groundmass. The more micaceous varieties are grey to black, and devoid of apparent phenocrysts; while the almost dioritic type from the Power-House Reserve presents a distinctly plutonic aspect, with only an occasional larger white felspar to bear witness to the porphyritic structure. In some localities, the rocks are curiously mottled by the presence of inclusions. These are mostly of a white felsitic rock in a typical dark porphyrite, but to a limited extent consist of still darker, more hornblendic varieties. The white inclusions sometimes present great resemblance to the albite-porphyries, but differ in the presence of occasional phenocrysts of hornblende. It is, apparently, to these mottled rocks that Mr. Campbell and Mr. Simpson have applied the term 'orbicular,' although the analogies with napoleonite are of the slightest. Another type of inclusion, occurring in the diorite-porphyrite of the Power-House Reserve, consists of coarsely-crystalline, black, 'basic segregations,' made up chiefly of hornblende and epidote, with subordinate carbonates and magnetite.

The rocks are never quite fresh, the felspars always containing more or less sericite, and occasionally a little zoisite. Other secondary minerals of common occurrence are uralite, epidote, chlorite, albite, carbonates, rutile, magnetite, pyrite, and quartz. The phenocrysts consist of apatite, felspars, hornblende, biotite, and rarely quartz; while the groundmass apparently consisted chiefly of felspars with subsidiary quartz, hornblende, and biotite, but is now much obscured by secondary minerals.

Apatite occurs sparingly in small but stout hexagonal prisms, and is generally turbid from alteration. In one rock it exhibits schillerization and distinct pleochroism. Hornblende is found in somewhat elongate pale-brown or green prisms, showing sharp cross-sections with prism and B-pinacoid faces, or longitudinal sections with the dome (011), and frequently twinned on A (100).

Pale uralite, preserving the octagonal cross-sections of pyroxene, has been observed in one rock; while actinolitic outgrowths on the hornblende-phenocrysts, and uralitic cores within them, in several other rocks, suggest that a small amount of pyroxene was originally present. Biotite is very abundant in those specimens which

Fig. 3.—*Albitized porphyrite, Power-House Reserve, showing an area of secondary albite, calcite, and epidote.* × 45.



[Hornblende and biotite, lying in the groundmass, have been omitted for convenience.]

approximate to plutonic rocks in structure, but assumes diminishing importance with the greater abundance of groundmass. It occurs in anhedral platy crystals, generally associated with the hornblende-phenocrysts, or often partly or wholly enclosed within them. The felspars are always euhedral as phenocrysts, and yield quadrate or hexagonal outlines according to the direction of section. Albite-twinning is predominant, both simple and polysynthetic;

pericline-twinning is rare; while Carlsbad twins have not been seen. Zoning is occasionally observed, but the zones do not always show a regular progression of decreasing basicity from centre to margin, since there is frequently an alternation between the same two species of plagioclase; nor is there any great difference in composition between the zones, for the extinction-angles do not differ by more than a few degrees. The centres of the crystals are too highly sericitized for exact determination; but there is generally a clear zone on the exterior, which agrees in refractive index, extinction-angles, and optical character with albite. The sericitized kernels are probably in some cases more basic, but in others they agree prefectly in optical characters with the clear border of albite. As undoubtedly secondary albite is present in some of the rocks, in nests associated with epidote and calcite (fig. 3, p. 656), it is probable that the phenocrysts which now consist of albite are albitized lime-soda felspars. The felspars of the groundmass are similar both in habit and in composition to the phenocrysts, and are never microlitic. Quartz is of rare occurrence as a phenocryst, in rounded forms like those observed in quartz-porphyries. In the diorite-porphyrite of the Power-House Reserve it occurs in a micropegmatitic fringe to the felspars, and in addition as a mosaic of secondary grains in the groundmass.

The view that the porphyrites are partly (and, in some cases, completely) albitized rocks is supported by the following analysis of a specimen (G.S.M. 2943) from a shaft in the Water Reserve No. 3398 E:—

	XXVIII.
SiO_2	63·05
TiO_2	0·97
Al_2O_3	14·04
Fe_2O_3	—
FeO	5·36
MnO	0·02
MgO	1·58
CaO	5·92
Na_2O	6·74
K_2O	0·62
H_2O+	0·26
H_2O-	0·04
CO_2	1·47
Total	100·07

Sp. gr. 2·75. Analyst—C. C. Williams, in E. S. Simpson, Bull. Geol. Surv. W. Austral. No. 6 (1902) p. 74.

In the description of this rock given by Mr. Simpson, it is stated to be decomposed, from which we may infer that the felspars are sericitized, while the presence of iron-ores and calcite is noted. The analysis should, therefore, contain iron sesquioxide. If the potash were present as orthoclase, the felspars would be, by calculation after the American method:—

	Per cent.
Orthoclase	3·67
Albite	56·96
Anorthite	6·18
Non-felspathizable lime	4·67

But, as the potash is probably present in sericite, and controls more alumina in this mineral than in orthoclase, and as the hornblende is presumably aluminous, the amount of alumina available for anorthite is probably not so great as the above calculation assumes, in which case the preponderance of the albite molecule will be more marked. In view of the variations shown by the porphyrites, and their interest as a hitherto unknown member of the spilite suite, the preparation of a larger series of analyses may be recommended as a task well worthy of the attention of the officers of the Geological Survey.

(*k*) The Albite-Porphyries.

These rocks occur in distinct dykes running approximately north-north-west and south-south-east through the quartz-dolerites and peridotites: they also, in close association with graphitic schists, occupy a considerable area of low country between 'The Mile' and Hannan's Lake, between the south-eastern and south-western dykes of quartz-dolerite. In hand-specimens they are white or pink: the white varieties being coarsely porphyritic and frequently deformed by shearing, while the pink varieties are less conspicuously porphyritic and with difficulty distinguished from some of the finer bleached quartz-dolerite greenstones. The distinction from the latter can usually be made, because of the almost universal occurrence of small apple-green inclusions in the pink porphyries.

Under the microscope, the porphyritic structure is well expressed by the presence of large euhedral crystals of albite, essentially similar to those found in the porphyrites. There is, however, a gradual diminution in the size of the albite-crystals, so that it becomes difficult to determine where phenocrysts end and groundmass begins; but the smallest crystals of the latter are allotriomorphic. The ground-mass is much obscured by secondary sericite, carbonates, and quartz: there is no suggestion, however, of orthophyric or trachytic structures.

The only evidence of any other original mineral is furnished by well-defined, often hexagonal areas of chlorite, carbonates, and sometimes fuchsite, surrounded by a rim of minute prisms of rutile. These are best developed in the strong dyke that runs from the Golden Gate Station through the Hainault, South Kalgurli, Perseverance, and Associated Mines, but are practically absent in the dyke associated with the graphitic schists in the Great Boulder Mine. They appear to be pseudomorphs of hornblende-phenocrysts; and, if this be the case, the resemblance between the porphyries and the porphyrites becomes still more marked.

The above description applies to the freshest specimens studied; frequently the rocks are extensively carbonated and sericitized, and the sheared specimens are practically quartz-sericite schists with augen of albite.

Three analyses of these rocks have been published by Mr. E. S.

Simpson,[1] of which only one (the first) is sufficiently fresh to admit of comparison with similar rocks from elsewhere. The analysis (XXVIII) of the albitized porphyrite is repeated from p. 657 for the purpose of comparison.

	XXIX.	XXX.	XXXI.	XXVIII.
SiO_2	68·12	65·51	62·16	63·05
TiO_2	0·62	tr.	0·16	0·97
Al_2O_3	15·97	18·12	14·98	14·04
Fe_2O_3	1·09	tr.	0·39	—
FeO	2·27	2·39	3·03	5·36
MnO	tr.	0·05	0·51	0·02
MgO	0·92	0·38	1·32	1·58
CaO	0·71	2·10	4·03	5·92
Na_2O	6·03	4·27	6·18	6·74
K_2O	1·29	3·28	1·59	0·62
H_2O+	0·29	0·46	0·25	0·26
H_2O-	0·17	0·07	0·07	0·04
CO_2	1·13	2·41	5·65	1·47
FeS_2	tr.	0·06	0·60	—
Totals	98·61	99·10	100·92	100·07
Bases soluble in *aqua regia*:—				
Al_2O_3	0·31	0·46	0·58	—
Fe_2O_3	1·09	tr.	0·39	—
FeO	2·27	1·73	3·03	—
MnO	tr.	0·05	0·51	—
MgO	0·58	0·38	1·32	—
CaO	0·35	1·99	4·03	—
Sp. gr.	2·60	2·72	2·72	2·75
Analyst	E. S. Simpson.	C. G. Gibson.	C. G. Gibson.	C. C. Williams.

XXIX. Albite-porphyry. G.S.M. 1743, main shaft, Boulder Bonanza, G.M.L. 1064 E.

XXX. Albite-porphyry. G.S.M. 1980, Hannan's Hundred Acres, G.M.L. 1226 E, 150-foot level.

XXXI. Albite-porphyry. G.S.M. 2219, 700-foot level, Brookman's Boulder, G.M.L. 749.

The felspars may be calculated as before, with the following result:—

	XXIX.	XXX.	XXXI.	XXVIII.
Orthoclase	7·62	19·38	9·40	3·67
Albite	52·67	35·39	52·25	56·96
Anorthite	1·78	0·55	none	6·18

The amount of potash may probably be taken as a measure of the sericitization, and this may explain why the porphyrite contains more albite than the porphyries. It appears to be the least sericitized rock of those analysed. Some of the freshest specimens of the albite-porphyries should exceed 60 per cent. of albite, judging from the sections.

[1] Bull. Geol. Surv. W. Austral. No. 6 (1902) p. 73.

(*l*) The Jaspers and Graphitic Schists.

An account of the petrology of Kalgoorlie would not be complete without some notice of the jasper-lodes and the bands of graphitic schist, which traverse rocks of almost every nature. Most of them run parallel to the foliation-planes of the enclosing rocks, but some are oblique, notably a strong jasper-lode east of Hannan's Reward Mine in the 'North End,' which cuts the foliation-planes at an angle of 50°.

The jaspers are light or dark siliceous rocks, generally with a fine banding which may be extravagantly contorted. The banding is due mainly to variations in the size of the grain of the quartz-mosaic of which the rocks are composed: it is not due to bands containing different minerals, as in the case of the hæmatite-jaspers of other goldfields. Sections reveal little beyond a very fine quartz-mosaic containing small sporadic rhombohedra of carbonates or limonite pseudomorphs of the same.

The jaspers are generally accompanied on each side by slaty rocks, which bear a close resemblance to ordinary sedimentary slates and phyllites, and similar rocks are also found replacing the jaspers along the strike. Few opportunities of tracing the downward continuation of the jaspers are available; but they appear in some cases to be replaced by graphitic schists (for instance, in the North End Development G.M.L. 1731 E, and in the Union Jack G.M.L. 535 E).

The band that has been most closely studied runs from the Boulder Main Reefs G.M. through the Great Boulder and Boulder No. 1 to the Golden Pyke G.M. and beyond. The outcrop can be traced in places by white slaty rocks, while jaspers and slaty rocks are seen in the railway-cutting east of the main shaft of Boulder No. 1 G.M. At the 100-foot level from Philip's Shaft in the Great Boulder G.M., the band consists of white quartz-sericite schists. A section of one of these shows a very fine quartz-mosaic, with much fine schistose sericite, a few minute prisms of rutile, and small pseudomorphs of limonite after pyrite or siderite. At greater depths this band is represented by graphitic schists, as may be seen at many places in the Great Boulder Mine. In section, the graphitic schists are almost opaque, from the presence of fine graphite dust and small crystals of pyrite; but the presence of quartz and sericite can generally be verified. A specimen from the eastern boring (from the main shaft at the 2350-foot level) contains quartz, carbonates, sericite, rutile, and clinochlore, in addition to graphite and pyrite. Wavy bands of sericite, deeply stained by fine graphite dust, wrap round clearer areas occupied by carbonates or by large pyrite-crystals enveloped by quartz and clinochlore.

At several places within this band of graphitic schists the presence of albite-porphyry has been verified, but it does not appear to form a continuous dyke. The same association of porphyry and graphitic schist occurs at the 400-foot level of the Union-Jack Mine. The graphitic schists are sharply marked off from the quartz-carbonate-sericite schists in which they occur, and also from the albite-porphyry. It seems most probable that they have

arisen from the schists and not from the porphyry; but the presence of the latter can hardly be accidental, for in a railway-cutting about 3 miles east of Coolgardie Dr. Maclaren has observed an analogous phenomenon. A narrow dyke of quartz-porphyry is intrusive through an amphibolite, and on each side of the dyke there is a band of graphitic schists about 5 feet wide. Unfortunately, neither the amphibolites nor the schists are fresh enough for microscopic study.

The impregnation of schists with graphite is not confined to bands traversed by porphyry-dykes. It is found, for instance, along fault-planes in the calc-schists. There can be no doubt whatever that the schists are of igneous origin, and that the graphite is of inorganic origin. Probably it has arisen from emanations given off by the porphyry magma, although the exact mechanism of its formation remains obscure.

Although in some places the graphitic schists crop out at the surface without much alteration, in others they are oxidized to a depth of over 100 feet, giving rise at the surface to white quartz-sericite schists. To this category, apparently, must be ascribed the rocks classed by Mr. Simpson as 'older sediments,' of which three analyses have been made.[1] The absence of contact-minerals in them militates against a theory of sedimentary origin for rocks so closely associated with intrusives, while the low magnesia and high soda percentages of the analyses make their derivation from albitized rocks probable. The analyses are as follows:—

	XXXII.	XXXIII.	XXXIV.
SiO_2	84·07	70·25	60·01
TiO_2	1·16	0·34	0·05
Al_2O_3	9·03	15·22	17·82
Fe_2O_3	0·42	1·00	0·54
FeO	0·45	0·87	1·65
MnO	tr.	tr.	0·09
MgO	0·24	0·12	1·69
CaO	0·21	0·14	5·86
Na_2O	1·64	3·46	2·79
K_2O	2·21	1·28	1·85
H_2O+	1·05	1·34	1·65
H_2O-	0·20	0·42	0·15
CO_2	0·07	0·02	5·50
FeS_2	0·04	5·93 *	1·88
Totals	100·79	100·39	101·53
Sp. gr.	2·66	2·73	2·71
Analyst	E. S. Simpson.	E. S. Simpson.	C. G. Gibson.

* Including 0·50 Cu.

XXXII. G.S.M. 1731. 'Dark-grey slate' from G.M.L. 917 E, Paringa Consolidated Mines, Ltd., Boulder.

XXXIII. G.S.M. 1732. 'Dark-grey sandstone' from the same lease.

XXXIV. G.S.M. 1739. 'Light-grey sandstone' from the 400-foot level, G.M.L. 3625 E, Hawk's View G.M., Kalgoorlie.

[1] Bull. Geol. Surv. W. Austral. No. 6 (1902) p. 77.

Whether the jasperoid rocks have arisen by a surface-silicification, as their absence in depth might suggest, or whether they are lenticular bodies following one another en échelon within the bands of graphitic schists, and thus not necessarily present in all cross-sections of the bands, cannot be decided on the evidence available. Dr. Lindgren[1] has suggested a deep-seated origin for the hæmatite-jaspers found in other goldfields of the State.

IV. Relationship of the Rocks.

While it is a matter for argument whether or not all the intrusive rocks from Kalgoorlie described above are related by differentiation from a common magma, they may be divided into groups, each of which consists only of members showing undoubted affinity one with the other.

Group α consists of the quartz-dolerites, dolerites, hornblende-dolerites, and pyroxenites. The first three of these rocks form different parts of the same mass, and show gradations from one to the other. The pyroxenites, although found in separate intrusions, betray their relationship with the quartz-dolerite by the occasional presence of micropegmatite. This group will be termed in the subsequent discussion 'the quartz-dolerite series.'

Group β contains the porphyrites and albite-porphyries. These rocks form a well-defined series with almost every gradation between the extremes represented, and their close relationship cannot be doubted.

Group γ contains by exclusion the peridotites.

Mr. Simpson[2] separated the last two groups from the first as 'newer eruptives,' his reasons being presumably that the albite-porphyries traverse the rocks of the quartz-dolerite series in well marked dykes, and that the serpentines of Hannan's Lake are relatively little-altered igneous rocks as compared with the amphibolites.

a) Relationship of the Peridotites to the Quartz-Dolerite Series.

The presence of the peridotites was first established by Mr. Simpson after a study of the serpentine and carbonated serpentine of Hannan's Lake. The interpretation of serpentines as altered peridotites is so well known, that one naturally regards a serpentine as an intrusive rock. The interpretation of amphibolites, on the contrary, has lagged behind; and, in consequence, those who have not made a study of the subject would tend to regard serpentine occurring among amphibolites as an intrusion into them. This is far from being necessarily the case. For instance, the lherzolites and ophites of the Pyrenees belong to the same magmatic series;

[1] 'Econ. Geol.' vol. i (1906) p. 542.
[2] Bull. Geol. Surv. W. Austral. No. 6 (1902) p. 72.

but, while the ophites show a uralitic change, the lherzolites are frequently serpentinized. The hornblende-schists and serpentines of the Lizard form an analogous case. On grounds of state of alteration, consequently, there is no reason to separate the serpentines from the quartz-dolerite series as 'newer eruptives.'

These remarks apply with still greater force to the derivatives of peridotites occurring in the 'North End.' These consist partly of talc-carbonate schists in the formation of which considerable pressure must have acted, and partly of magnesite-rocks and fuchsite-magnesite-rocks as the metasomatic products in the areas traversed by auriferous veins. They are, therefore, pre-foliation and pre-gold rocks, in the same sense as the rocks of the quartz-dolerite series.[1]

Further, the distribution of the peridotite and pyroxenite derivatives in the dumps of the eastern part of the 'North End' is such as to suggest that the pyroxenites occur as narrow bands in a large mass of peridotite: a mode of occurrence compatible with the later intrusion of the pyroxenite, or with the contemporaneous intrusion of the two rocks as a banded complex, but scarcely with the later intrusion of the peridotite.

It is most probable, therefore, that the peridotites form the ultrabasic pole of the quartz-dolerite series, in support of which view many analogies might be quoted. The only observation that creates any difficulties is that the peridotite-intrusion in the eastern part of the 'North End' has determined a contact-alteration in the surrounding fine-grained greenstones, while the larger quartz-dolerite intrusion has apparently no such aureole. This fact notwithstanding, the bulk of evidence suggests that the peridotites were the earliest intrusives, followed closely by the pyroxenites, and at an interval by the quartz-dolerite and its local variants.

(*b*) Relationship of the Porphyries and Porphyrites to the Quartz-Dolerite Series.

The albite-porphyries form narrow dykes running north-north-west and south-south-east in the quartz-dolerites, which have the same general trend. Both rocks are locally schistose, and the planes of foliation strike parallel with the trend of the rocks. It is, therefore, obvious that the shape of the intrusions of both types of rock was determined by pressures similarly directed to those which subsequently brought about their schistosity. Both must have been intruded during intervals of relief of pressure in the course of one great epoch of earth-pressure. On the whole, this mode of occurrence is in favour of a close age-relationship, and therefore of the probability of a magmatic relationship between the two rocks. Nevertheless, in contact-altered goldfields of the Coolgardie type a somewhat similar mode of occurrence is observed.

[1] See J. A. Thomson, 'The Classification of the Rocks of the Western Australian Goldfields' Geol. Mag. dec. 5, vol. ix (1912) pp. 213–14.

The contact-altered hornblende-schists are penetrated by dykes of quartz-porphyry, which have the same trend as the foliation of the schists, and yet clearly belong to the granite series. In no case of this kind, however, has it yet been demonstrated that the foliation of the hornblende-schists is parallel to the major axes of the intrusives from the metamorphism of which they have arisen. Although the Kalgoorlie albite-porphyries are sometimes very little altered, while the quartz-dolerites, when not metasomatized, are always metamorphosed into amphibolites, this difference of their state of alteration need not prevent us from considering them as of approximately the same age: for it is well known that the original pyroxenes and lime-soda felspars of quartz-dolerites are unstable under pressure-metamorphism, while under the same conditions the albite of the porphyries is eminently stable.

Two facts speak strongly for a magmatic relationship between the albite-porphyries and the quartz-dolerite series. The first is the close chemical similarity between the former and rocks associated with quartz-dolerites in other parts of the world; the second is the albitization of the quartz-dolerites. These two facts are really interdependent.

The following table of analyses illustrates the close similarity of

	XVII.	XXXV.	XXXVII.	XXIX.	XXXVI.	XXXVIII.
SiO_2	48·86	50·55	48·02	68·12	71·18	71·26
TiO_2	0·22	1·58	3·36	0·62	0·48	0·28
Al_2O_3	14·91	15·00	13·03	15·97	14·89	11·87
Fe_2O_3	—	2·54	2·11	1·09	2·11	0·10
FeO	11·13	7·90	9·99	2·27	1·21	2·12
MnO	0·90	—	tr.	tr.	—	0·06
MgO	7·65	6·25	4·21	0·92	0·14	1·08
CaO	12·19	7·85	9·77	0·71	0·82	2·88
Na_2O	2·58	3·53	2·17	6·03	6·85	6·73
K_2O	0·19	1·10	0·49	1·29	1·70	0·054
H_2O+	1·51	3·14	4·27 *	0·29	0·64	2·71 *
H_2O-	0·04	0·55	1·05	0·17	0·24	0·62
P_2O_5	—	—	0·395	—	—	0·10
CO_2	none	—	—	1·13	—	—
F	—	—	0·08	—	—	0·009
FeS_2	—	—	1·24	—	—	0·256
Totals ...	100·18	99·99	100·18	98·61	100·26	100·12
Analyst ...	C. C. Williams.	J. V. Elsden.	J. D. Falconer.	E. S. Simpson.	J. V. Elsden.	J. D. Falconer.

* H_2O+ and CO_2 are reckoned together.

XVII. Quartz-dolerite amphibolite. Kalgoorlie. (See also p. 645.)
XXIX. Albite-porphyry. Kalgoorlie. (See also p. 659.)
XXXV. Diabase (quartz-dolerite). Carn-Llidi, St. David's Head. J. V. Elsden, Q. J. G. S. vol. lxiv (1908) p. 281.
XXXVI. Soda-aplite. Carn-Llidi, St. David's Head. *Ibid.* p. 283.
XXXVII. Quartz-diabase. Kettlestoun Quarry. J. D. Falconer, Trans. Roy. Soc. Edin. vol. xlv, pt. 1 (1906) p. 147.
XXXVIII. Segregation-vein, Kettlestoun Quarry. *Ibid.*

the association of rocks at Kalgoorlie with those of St. David's Head (South Wales), and the Kettlestoun Quarry, Bathgate Hills (Scotland).

The similarities displayed in these analyses are too striking to be accidental, and must be explained away if the albite-porphyries are considered not to belong to the quartz-dolerite series.

Albitization—that is, the secondary alteration of lime-soda felspars, by which albite-molecules are substituted for anorthite-molecules—was first brought into prominence by Mr. E. B. Bailey & Mr. G. W. Grabham [1] in the case of some Carboniferous lavas at Arthur's Seat, and in some quartz-dolerites of the Central Valley of Scotland. The secondary albite is sometimes sericitic, and is accompanied by chlorite and carbonates. Unfortunately, we are left in doubt as to the effect of the alteration on the pyroxenes and iron-ores. The albitization is ascribed to the action of concentrated solutions of sodium carbonate, which are derived from the magma itself. An interesting point is, that while the most basic felspars in any given rock are the first to be albitized, the alteration operates with greatest freedom on the most acid rocks.

Mr. H. Dewey & Dr. J. S. Flett [2] claim albitization as a juvenile alteration affecting certain rocks of the spilitic suite, a series of volcanic and intrusive rocks whose

'essential characteristics are the abundance of soda-felspar and the remarkable frequency with which they have been albitized.' (*Op. cit.* p. 246.)

If their contention, that the spilite suite is a fundamental division of igneous rocks comparable with the Atlantic and Pacific suites, be correct, then it will at once be conceded that the albite-porphyries of Kalgoorlie, from their richness in albite and their resemblance to the soda-felsites of Great Britain, find their place in the spilite suite. Their contention gains considerable weight from the observations of Mr. W. N. Benson,[3] who has found spilites associated with radiolarian cherts in Eastern Australia in exactly the same manner as they occur in Great Britain.

But there are other rocks in Western Australia, which on chemical and mineralogical grounds must also belong to the spilite suite. These are the albite-granites and albite-pegmatites that occur in some of the goldfields and in all the tin and tantalum fields. The analyses in the following table (p. 666) are quite comparable with those of the more acid members of the suite in Great Britain quoted by Mr. Dewey & Dr. Flett (*op. cit.* p. 209).

[1] 'Albitization of Basic Plagioclase-Felspars' Geol. Mag. dec. 5, vol. vi (1909) pp. 250–56.

[2] 'British Pillow-Lavas & the Rocks Associated with them' *Ibid.* vol. viii (1911) pp. 202–209 & 241–48.

[3] 'Spilite Lavas & Radiolarian Rocks in New South Wales' *Ibid.* vol. x (1913) pp. 17–21.

ANALYSES OF ALBITE-GRANITES, ALBITE-PEGMATITES, ETC., FROM WESTERN AUSTRALIA.

	XXXIX.	XL.	XLI.	XLII.	XLIII.	XLIV.
SiO_2	72·77	70·82	70·27	68·36	68·11	66·43
TiO_2	0·55	0·35	0·12	—	0·74	0·68
Al_2O_3	13·87	15·56	16·11	18·74	15·77	16·22
Fe_2O_3	tr.	0·51	0·97	none	0·11	0·54
FeO	2·79	1·73	1·22	1·15	2·99	1·17
MnO	0·22	0·13	0·20	0·45	0·16	none
MgO	0·40	0·87	1·87	0·54	1·75	1·60
CaO	1·60	2·20	1·76	0·39	3·79	5·88
Na_2O	4·18	5·57	4·64	10·22	4·58	6·35
K_2O	2·81	1·94	0·64	0·07	0·76	0·35
H_2O+	0·29	0·27	1·08	0·93	0·86	0·26
H_2O-	0·02	0·05	0·10	none	0·11	0·20
P_2O_5	—	tr.	0·12	—	0·28	0·40
CO_2	0·24	0·40	0·20	—	0·21	none
FeS_2	tr.	0·20	0·09	—	0·17	0·04
Totals ...	99·74	100·60	99·39	100·85	100·39	100·12
Sp. gr.	2·69	2·64	2·70	2·64	2·74	2·70
Analyst ...	J. H. Brooking.	E. S. Simpson.	E. S. Simpson.	E. S. Simpson.	E. S. Simpson.	C. C. Williams.

XXXIX. G.S.M. 5392. 'Porphyry,' Duffers' Creek, near Marble Bar, Pilbara Goldfield. Bull. Geol. Surv. W. Austral. No. 15 (1904) p. 12.

XL. G.S.M. 4426. 'Felspar-porphyry,' Mount Catherine Range, Yerilla, North Coolgardie Goldfield. *Ibid.* No. 11 (1903) p. 7.

XLI. G.S.M. 8139. 'Soda-granite,' well, 25 chains south of No. 2 Tank, Ravensthorpe. *Ibid.* No. 35 (1909) p. 21.

XLII. G.S.M. 5397. 'Pegmatite (tin-matrix),' Moolyella, Pilbara Goldfield. *Ibid.* No. 15 (1904) p. 12.

XLIII. G.S.M. 8151. 'Soda-granite,' western well on W.R. 7517, Ravensthorpe. *Ibid.* No. 35 (1909) p. 21.

XLIV. G.S.M. 6880. 'Oligoclase-pegmatite,' west of Lily G.M.L. 1494, Cue. *Ibid.* No. 29, pt. 2 (1907) p. 53.

There are no such albite-granites known near Kalgoorlie, although the presence of tantalum minerals near Coolgardie suggests their presence in that neighbourhood. Nothing is as yet known as to the relative ages of the albite-granites and the more normal orthoclase- or microcline-granites which are intrusive into, and have strongly altered, the hornblende-schists of goldfields of the Coolgardie type. In the Ravensthorpe district, from which only albite-granites and quartz-keratophyres among the acid rocks have been described, there are amphibolites showing considerable contact-alteration, presumably by these granites. If these amphibolites are correlated in age with those of Kalgoorlie, and it be found that the albite-granites are unrelated magmatically to the amphibolites, then the presumption is, either that the albite-porphyries of Kalgoorlie are unrelated to the rocks of the quartz-dolerite series, or else that there are rocks of more than one age in Western Australia belonging to the spilitic suite. A detailed study of a

district, such as Ravensthorpe, in which the albite-granites are developed, should help to throw light on these questions. At present, our knowledge of the albite-granites does not materially affect the discussion of the phenomena at Kalgoorlie.

Quartz-dolerites are also admitted by Mr. Dewey & Dr. Flett among the rocks of the spilite suite: both because of their occurrence along with the Cornish spilites and albite-dolerites, and because of their occasional (but incomplete) albitization in Scotland, to which may be added also, because of their association, as at St. David's Head, with soda-aplites. It is clear, however, that all quartz-dolerites cannot find a place here. Those of the Tertiary igneous series of Britain, for instance, are associated with rocks of distinctly Pacific type, such as granophyres, and not with soda-felsites or soda-granites. Quartz-dolerites appear, therefore, to be 'diphiletic rocks,'[1] and it would be interesting to know whether any constant mineralogical or chemical peculiarities (such, for instance, as the presence of enstatite-augite) are found in those associated with the spilites.

At Kalgoorlie, the absence of granophyres, the association of the albite-porphyries with the quartz-dolerites, and the albitization of the quartz-dolerites, are sufficient grounds for the classification of the latter rocks in the spilitic suite, and for concluding that the porphyries and porphyrites belong to the same series of intrusions as the quartz-dolerites. Nevertheless, the analogies with the conditions in Britain are not complete, for the albitization appears to have been effected in a somewhat different manner. Mr. Dewey & Dr. Flett remark:

> 'Clearly, then, the albitization is a process intimately connected with the nature of the individual rock; the spilites and quartz-free diabases show it, but the quartz-diabases do not..... The albitization is not characteristic of the whole suite, but is especially frequent in certain members of it, such as the spilites and diabases, while others like the quartz-diabases are less liable to this change. It is not due to weathering or shearing. Good evidence exists to prove that the albitization took place soon after the rocks had solidified, and consequently it may be grouped among the post-volcanic or juvenile changes of rock-masses.' (Geol. Mag. dec. 5, vol. viii, 1911, pp. 207 & 246.)

At Kalgoorlie the albitization has affected quartz-dolerites, but it does not appear to have been caused by solutions emanating from the actual magma that consolidated relatively near the surface as quartz-dolerite. Before discussing this phase of the subject, it is necessary to consider whether the albitization preceded or succeeded the uralitization of the quartz-dolerites. It is just here that the greatest difficulty in the petrography of Kalgoorlie presents itself. Some specimens collected near the boundary of the amphibolites and the greenstones certainly seem to indicate that the albitization has been effected on the amphibolites; but, on the other hand, the perfect preservation of the felspar-prisms in many of the greenstones and bleached greenstones is difficult to account for, if these

[1] See J. A. Thomson, 'On Rock-Specimens from Central & Western Australia' Journ. & Proc. Roy. Soc. N.S.W. vol. xlv (1911-12) p. 316.

felspars were first saussuritized. On the whole, without being quite positive on the point, I favour the view that the albitization preceded the uralitization, and, further, that (as in the case described by Bailey & Grabham) the more acid part of the quartz-dolerite mass was affected by the albitization, while the more basic part was not, and was subsequently converted into amphibolite. Nevertheless, if it should be subsequently shown that the uralitization preceded the albitization, it would not invalidate the general conclusions of this paper, for it is certain that the quartz-dolerites were partly sheared before the intrusion of the porphyries.

Although it is difficult to give actual proof of it, there is every reason to believe that the lodes as such were formed after the intrusion of the porphyries. The latter never cut the lodes, but sometimes form their walls. Now, if the albitization were due to emanations from the cooling quartz-dolerite magma, it preceded the intrusion of the porphyries, which did not take place until the quartz-dolerite had been sheared, and, in consequence, the formation of the lodes must be due to a later set of solutions. But the rocks most intimately associated with the lodes, and on which the vein-solutions have left their mark: namely, the bleached greenstones, do not differ essentially from the greenstones. Albitization and the concomitant processes that gave rise to the greenstones constituted the incipient vein-alteration, extreme carbonation and sericitization with minor silification the final vein-alteration. Consequently, if the lodes are later than the porphyries, the albitization and accompanying changes must have followed, or at least must have continued until after the intrusion of the porphyries. Confirmative evidence of this view is afforded by two observations: first, that the porphyrites have been albitized, and that some of the porphyries appear to be albitized porphyrites; and, secondly, that the greatest development of the bleached greenstones lies in those parts of the quartz-dolerite mass that surround the porphyry intrusions.

The solutions producing the alterations at Kalgoorlie must have been very similar in nature to those that produced the albitization in Britain. Mr. Dewey & Dr. Flett have described the latter as follows:—

'The composition of the pneumatolytic emanations cannot be exactly defined, but it is certain that they consisted of water and soda and silica in solution; probably also carbonic acid was abundant, and many other substances may have been present.' (Geol. Mag. dec. 5, vol. viii, 1911, p. 246.)

The early solutions in Kalgoorlie which caused the albitization must have been of this nature, with soda and silica relatively abundant; while the later solutions must have contained more carbonic acid and, perhaps, also potash. The solutions probably altered gradually in nature as the underlying magma cooled, and in the late stage at which the lodes were formed 'many other substances' must certainly have been present; but their discussion does not come within the scope of this paper, and must await a fuller

treatment of the mineralogy of the lodes. The earlier strongly albitizing solutions affected only the quartz-dolerites, the porphyrites, and the porphyries, which were probably the rocks that had consolidated last. The later solutions, while ascending most freely in the old channels, also found new planes of weakness in the older rocks: namely, the fine-grained amphibolites and the serpentines, and brought about their alteration into the fine-grained greenstones and 'calc-schists,' and the talc-carbonate schists and magnesite-rocks.[1]

(c) The Connexion of Gold and Tellurides with Igneous Magmas.

At this point a digression may be made, to indicate the widely-different kinds of igneous rocks with which gold and tellurides are genetically associated. Dr. J. M. Maclaren[2] has rendered this discussion easy by his ingenious and illuminating classification of goldfields on grounds of geological occurrence and geographical distribution. His first basis of classification of primary gold deposits is, however, petrological. They are divided into:—

1. Those connected with the extrusion of intermediate or basic rocks (andesites or diabases).
2. Those connected with the extrusion of acid rocks of granodioritic type.

The first group is again divided into:—

(i) Archæan goldfields of hornblende-schists and amphibolites: for instance, Western Australia (Kalgoorlie), India (Kolar), etc.
(ii) Pre-Cambrian goldfields, where diabase- or diorite-dykes penetrate Archæan schists: for instance, Western Australia, India (Dharwar), South Africa, etc.
(iii) Tertiary andesite goldfields: for instance, Transylvania, New Zealand, California, Colorado (Cripple Creek), etc.

Petrologists will at once demur to a classification which brings the phonolite and related rocks of Cripple Creek into the same division as the andesites of Transylvania and New Zealand. If a preliminary classification on petrological grounds is sought, it must be based in the first place on the fundamental divisions of igneous rocks into the Pacific, Atlantic, spilite, and charnockite suites. Unfortunately, petrology has not reached finality in the definition

[1] The development of the theory of the spilitic suite in Great Britain took place some time after I had left Kalgoorlie, and when I had no longer access to most of the microscopic slides. Consequently, there are some points in connexion with it that have not received the attention which otherwise might have been given to them. Of these, the most important are the relative dates of uralitization and albitization of the quartz-dolerites, and the proof that the intrusion of the albite-porphyries preceded the formation of the lodes. These points must be left to subsequent investigators.

[2] 'Gold: its Geological Occurrence & Geographical Distribution' London, 1908, pp. 44–45.

of these fundamental divisions, at least on chemical grounds. Nevertheless, the following classification may be suggested:—

Goldfields genetically associated with

(1) Rocks of Pacific type, for instance:
- (*a*) andesites and dacites (New Zealand, Transylvania, etc.);
- (*b*) granodiorites (East Australia, North America, etc.);
- and probably (*c*) dolerites (India);
- (*d*) hornblende-schists (India).

(2) Rocks of Atlantic type, for instance:
- (*a*) phonolites (Cripple Creek);
- (*b*) foyaite (Portobello, New Zealand).[1]

(3) Rocks of spilitic type, for instance:
- (*a*) quartz-dolerite and albite-porphyry (Kalgoorlie);
- (*b*) albite-granite (Ravensthorpe, Western Australia).

It is interesting to note that tellurides are found in goldfields belonging to each of the major divisions proposed above, with andesites of Pacific type in Transylvania, with phonolites of Atlantic type at Cripple Creek, and with quartz-dolerites and albite-porphyries of spilitic type at Kalgoorlie. The two most important gold-occurrences not connected with rocks of Pacific type are telluride fields.

(*d*) The Relationship of the Quartz-Dolerite Series to the Fine-Grained Amphibolites and Greenstones.

The facts that are clear are that the fine-grained amphibolites and greenstones are the older series, and have been contact-altered by the peridotites and porphyrites. It has already been suggested that the former rocks are most naturally regarded as an altered series of lavas or tuffs. If this view be accepted, it remains to be considered whether this volcanic series arose from the same magma as the intrusives: that is, whether the relationship between the two series is analogous to that of the lavas and intrusives of so well-known a district as Skye. Had the fine-grained amphibolites, or some of them at least, the composition of spilites, a positive answer could at once be given to this question. But, although no analysis of the Kalgoorlie examples has yet been made, it is unlikely that they will be found comparable with the spilites, and most probable that they will be found to agree with normal (labradorite) basalts. Even then, it will still be possible to regard them as magmatically related to the quartz-dolerite series: for it is clear that the albitizing power of the magma was a late development during intrusion and cooling. The question, however, is best left open at present, until a closer study and comparison of the fine-grained amphibolites and their relatives in other goldfields has been made.

[1] See G. H. F. Ulrich, in F. W. Hutton & G. H. F. Ulrich, 'Report on the Geology & Goldfields of Otago' Dunedin, 1875, pp. 165–68; and P. Marshall, 'The Geology of Dunedin' Q. J. G. S. vol. lxii (1906) pp. 391–93.

V. Summary and Conclusions.

In this paper an attempt has been made to show that, by means of detailed microscopical and chemical study, carried out hand in hand with mapping, it is possible to unravel the structure of such a district of serpentines, amphibolites, and greenstones as most of the Western Australian goldfields present. The petrographical methods on which most insistence has been placed are the interpretation of pseudomorphs of earlier minerals and the recognition of relict-structures revealing the original inter-relationships of these minerals. By these methods a fairly clear picture of the original rocks may be restored, while a knowledge of the chemical composition of the rocks in question gives valuable aid in checking or corroborating the results obtained. It is found that most of the coarse-grained amphibolites of the goldfields of Western Australia were originally pyroxenites, hornblende-dolerites, dolerites or gabbros, and quartz-dolerites or quartz-gabbros, and all these types occur in Kalgoorlie associated with serpentines derived from pyroxene-peridotites. In addition, there is present in Kalgoorlie and elsewhere an older series of fine-grained amphibolites without recognizable relict-structures, but having the chemical composition of basalts. Corresponding to all of the above types of amphibolite there are greenstones consisting mainly of chlorite, carbonates, and sericite; but greenstones that were formed from the pyroxenites and hornblende-dolerites are rare and unimportant. In Kalgoorlie a distinctive feature, not recorded elsewhere in the State, is the abundance and importance of albite-bearing greenstones obviously formed by the albitization of quartz-dolerites, and also the presence of dykes of albite-porphyry and albitized porphyrites, which clearly have a close connexion with the albitization. On these grounds it is suggested that the whole series of intrusive rocks at Kalgoorlie belongs to the spilitic suite, and that the formation of the telluride gold-lodes is due to after-emanations of the spilitic magma. A classification of auriferous deposits according to their genetic connexion with magmas of Atlantic, Pacific, or spilitic facies is a natural corollary of this view.

While much of the latter part of the paper may be regarded as suggestive rather than conclusive, it furnishes a basis for future petrological studies in the other goldfields of Western Australia. Such studies will in turn throw light on some of the complexities of Kalgoorlie.

To Dr. J. M. Maclaren I am indebted for permission to publish those parts of this paper which refer exclusively to Kalgoorlie: for the work was carried out on his behalf, in the preparation of a report on the economic geology of certain groups of mines. The field-work was carried out in association with him, and the bearing of the petrological results was discussed with him at every turn. But, after the development of the theory of the spilitic suite in Great Britain, certain views as to the relationship of the rocks,

and more particularly as to the importance of the porphyries in determining the districts of albitization, were elaborated by me independently of Dr. Maclaren, and he cannot be considered as committed to them.

Much kind assistance in providing laboratory and library facilities in Kalgoorlie was given by the Chamber of Mines of Western Australia, the Lecturers of the Kalgoorlie School of Mines, and by Mr. T. Blatchford and Mr. C. de J. Grut. Mr. A. Gibb Maitland, Mr. H. P. Woodward, and Mr. C. G. Gibson, of the Geological Survey of the State, were ever ready to give information as to the conditions in other goldfields, and to lend specimens, slides, maps, and books. The extensive series of analyses, made principally by Messrs. E. S. Simpson, C. G. Gibson, & C. C. Williams, has been freely drawn upon, and has obviated the necessity of spending much time on analytical work. Without the painstaking labour that the preparation of these analyses has involved, the conclusions of this paper would lose much in value. Petrologists can never underestimate the debt that they owe to chemists, whose work makes little show in proportion to the time spent upon it.

Any success that I may have attained in unravelling the structure of the field by the interpretation of the amphibolites is entirely due to the experience gained by association with Dr. J. S. Flett, F.R.S., both in the study of Scottish and Cornish epidiorites and amphibolites in the laboratories of the Geological Survey, and in field-work in the Lizard District.

VI. Postscript. [April 28th, 1913.]

The manuscript of the main part of this paper was despatched in the confident anticipation that a series of line-drawings and photographs, which were prepared in Kalgoorlie during 1910, would be received from Dr. Maclaren in time to follow by an early mail. Dr. Maclaren has now written to say that they have unfortunately been lost, and that, still more unfortunately, the slides from which they were prepared are also missing. In these circumstances, it is possible to present only a few figures prepared from such slides as I possess in my own collection, in which only the rarer or more obscure types of Kalgoorlie rocks are represented. Fortunately, a recent mail has brought an advance-copy of a bulletin on Kalgoorlie in which is included a series of clear photographs of representative Kalgoorlie rocks by Mr. H. Bowley & Mr. C. G. Gibson.[1] Reference to these figures and to those previously published by Mr. Larcombe will be facilitated by the list given below:—

Abbreviations:—A=Simpson & Gibson, *op. cit.*
B=C. O. G. Larcombe, Proc. Austral. Inst. Min. Eng. vol. v, no. 2 (1911).

[1] E. S. Simpson & C. G. Gibson, 'Contributions to the Study of the Geology & Ore-Deposits of Kalgoorlie, East Coolgardie Goldfield' Bull. Geol. Surv. W. Austral. No. 42. Dated 1912, but issued in 1913.

Ancient sediments. A :—Figs. 1–3.
B :—Pls. X–XII ; XIV, fig. 1.
Fine-grained amphibolites. A :—Figs. 5, 6, 10, & 42.
Fine-grained greenstone (with chloritoid). A :—Fig. 47 ('Ottrelite-schist').
Calc-schists. B :—Pl. XIV, fig. 2 ; Pl. XVIII. ('Metamorphic tuffs.')
Serpentine. A :—Fig. 48.
Pyroxenite (amphibolite). A :—Fig. 8.
Quartz-dolerite-greenstones and bleached greenstones.
A :—Figs. 7, 33, & 34.
B :—Pls. XIX–XXV ; LXII–LXIV. ('Quartz-andesite, granophyric dacite, aphanite.')
Lode-matter in the quartz-dolerite-greenstones.
A :—Figs. 26, 27, & 32.
B :—Pls. L, LI, & LXI.
Porphyrites. A :—Figs. 11 & 13.
Albite-porphyries. A :—Fig. 14.
B :—Pl. XXVIII.
Jaspers and graphitic schists. A :—Fig. 17.
B :—Pls. XXVII & XXVIII.

In the Bulletin above cited, Mr. Gibson amplifies his previous account of the geology of Kalgoorlie by describing the chief rock-types in some detail. Mr. Simpson also adds further details of the petrography in an account of the minerals found in the field, and discusses the alterations of the rocks in a chapter dealing with the ores. Several new analyses by Mr. Bowley are included in the Bulletin.

While the classification of the individual rocks adopted by Mr. Gibson is substantially the same as that given in this paper, the treatment of their relationships is in reality fundamentally different. Neither Mr. Gibson nor Mr. Simpson has recognized the albitization of the quartz-dolerites and porphyrites, or the close connexion between this alteration and the intrusion of the porphyrites and porphyries. This leads the first-named writer to state that the porphyrites are of no economic importance ; whereas the discovery of porphyrites or albite-porphyries outside the Kalgoorlie area should be of great value to the prospector, as indicating an area of possible albitization with a heightened possibility of discovering telluride-lodes. So far from recognizing the albitization, Mr. Gibson states that the felspars of the greenstones are frequently saussuritized : an assertion that is in practical contradiction to his statement that epidote is rare, and when present is associated with chlorite.

Mr. Simpson, in discussing the alterations that have given rise to the ores and the wall-rocks of the lodes, still adheres to his previously expressed conclusion that the coarse greenstones have passed through an amphibolitic stage, without, apparently, considering the possibility of their direct derivation from the original rock, or recognizing that the rocks from which they were derived were, on the whole, more siliceous than those now represented by amphibolites. Nevertheless, the new analyses help to confirm

this statement, for they show that the amphibolites (within the Kalgoorlie area proper) rarely contain more than 50 per cent. of silica, the actual figures being 46·26, 46·38, 47·12, 48·86, 49·06, and 50·72.[1] Now, it may be unhesitatingly asserted that the average silica-percentage of quartz-dolerites exceeds 50; and, since the greenstones contain, on the whole, more micropegmatite than an average quartz-dolerite, and more than the amphibolites, the original silica-percentage of the rocks from which they were derived must have exceeded 51 and may have approached 54. This phenomenon of the alteration selecting the most acid part of the intrusion has a parallel in the case of the juvenile albitization described by Bailey & Grabham, and certainly makes it probable that the mode of alteration was in each case similar.

As I have already stated in the body of this paper, there are certain epidotic greenstones in the 'North End' that give colour to Mr. Simpson's view. A full discussion of the subject would involve a long digression on the problem of uralitization, on which very contradictory opinions have been expressed in recent works, and such a discussion would be out of place here. It is, in my view, quite conceivable that the later carbonating solutions, which found the peridotites already altered to serpentines, may have found the more basic part of the quartz-dolerites already converted into amphibolites, and may have further altered these into epidotic greenstones. Another alternative mode of origin of these greenstones, equally in conformity with the theory of juvenile albitization, is that in the North End the albitization and accompanying changes were only partial, and that subsequently uralitization and saussuritization affected those parts of the original pyroxenes and lime-soda felspars that were left intact. Obviously, the problems in Kalgoorlie are very complex, and, despite the large amount of study that they have received in recent years, there is still much left for the petrologist to unravel.

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[1] These amphibolites are not all derived from quartz-dolerites, the first ($SiO_2 = 46·26$, $MgO = 19·65$, $CaO = 6·94$) being certainly a lustre-mottled amphibolite

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Discussion.

Dr. J. V. Elsden said that the Author had made a valuable contribution, both to practical and to theoretical geology. From the practical standpoint, the speaker would like to know more regarding the distribution and origin of the gold and the relation of the auriferous veins to the quartz-dolerites. From the theoretical point of view, the evidence of magmatic differentiation, adduced in the paper, appeared to be of an especially interesting character. With regard to the extensive albitization of the rocks, this was a phenomenon to which petrologists were now giving much attention, and the Author's observations would be widely appreciated.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LXIX.

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1912–1913.

November 6th, 1912,

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communications were read :—

1. 'A Contribution to our Knowledge of Wealden Floras, with Special Reference to a Collection of Plants from Sussex.' By Albert Charles Seward, M.A., F.R.S., F.L.S., F.G.S., Professor of Botany in Cambridge University.

2. 'Notes on the Discovery of Fossiliferous Old Red Sandstone in a Boring at Southall, near Ealing.' By Ernest Proctor, A.R.C.S. (Communicated by Prof. W. W. Watts, Sc.D., F.R.S., V.P.G.S.) With a Note on the Fish-Remains, by Arthur Smith Woodward, LL.D., F.R.S., F.L.S., Sec.G.S.

The following lantern-slides and specimens were exhibited :—

Lantern-slides of Wealden plants, exhibited by Prof. A. C. Seward, M.A., F.R.S., F.L.S., F.G.S., in illustration of his paper.

Plaster cast of the rostrum of *Protosphyræna stebbingii*, A. S. Woodward, from the Lower Chalk, reconstructed from two specimens, the basal piece having been found at Betchworth, Surrey (Coll. W. P. D. Stebbing), the middle piece at Ferriby (Coll.

T. Sheppard), and the end of the rostrum at Betchworth (Coll. W. P. D. Stebbing), exhibited by Dr. A. Smith Woodward, F.R.S., F.L.S., Sec.G.S.

Plant-remains, with erratics, from the Chalk Marl of Burham, near Rochester; also Chloritic Marl, with phosphatic nodules, from the same locality, exhibited by G. E. Dibley, F.G.S.

November 20th, 1912.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

Dr. Ralph Arnold, 921 Union Oil Buildings, Los Angeles (California), U.S.A.; the Rev. William Looker, Ouseley House, Gaywood Road, King's Lynn; and Walter Hugh Phillips, Palana, Bikanir State (Rajputana), India, were elected Fellows of the Society.

The following communications were read:—

1. 'On the Hafslo Lake and the Solvorn Valley (Norway).' By Horace Woollaston Monckton, Treas.L.S., F.G.S.

2. 'On the Genus *Aulophyllum*.' By Stanley Smith, B.A., M.Sc., F.G.S.

The following photographs and lantern-slides were exhibited:—

Photographs and lantern-slides, exhibited by H. W. Monckton, Treas.L.S., F.G.S., in illustration of his paper.

Lantern-slides, exhibited by Stanley Smith, B.A., M.Sc., F.G.S., in illustration of his paper.

December 4th, 1912.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

Carleton Charles Joyce Atkin, Gwelo (Southern Rhodesia); Archibald William Robertson Don, B.A., Trinity College, Cambridge; William Forbes-Leslie, M.B., 22 Marina Court Avenue, Bexhill-on-Sea; Frederick Lyle Grützmacher, Lecturer in Mineralogy, Geology, & Chemistry in the Rockhampton Technical College (Queensland); Fred Hardy, Government Lecturer in Natural & Agricultural Sciences, Bay Mansions, Bridgetown, Barbados (British West Indies); Sydney Henry Harman, Tavoy (Lower Burma); Eric Mackay Heriot. 19 Campden Hill Gardens,

Kensington, W.; Ardesir Naservanji Peston Jamas, M.A., B.Sc., Ahmed Building, Grant Road, Bombay (India); William Bernard Robinson King, B.A., Jesus College, Cambridge; Frederick George Meachem, The Hermitage, Wall Heath, near Dudley; and Archibald Lewis Shrager, Assoc.R.S.M., care of Messrs. H. S. King & Co., 65 Cornhill, E.C., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Lower Palæozoic Rocks of the Cautley District (Yorkshire).' By John Edward Marr, Sc.D., F.R.S., V.P.G.S.

2. 'The Trilobite Fauna of the Comley Breccia-Bed (Shropshire).' By Edgar Sterling Cobbold, F.G.S.

3. 'Two Species of *Paradoxides* from Neve's Castle (Shropshire).' By Edgar Sterling Cobbold, F.G.S.

The following specimens, lantern-slides, and maps were exhibited:—

Specimens exhibited by Dr. J. E. Marr, F.R.S., V.P.G.S., in illustration of his paper.

Specimens of lantern-slides exhibited by E. S. Cobbold, F.G.S., in illustration of his paper.

Geological Survey of England & Wales—1-inch Geological Map, n. s. Sheet 355, Kingsbridge; Sheet 356, Start Point; and Sheet 359, The Lizard, 1912, presented by the Director of H.M. Geological Survey.

Geological Survey of Scotland—Index-Map, 1 inch = 4 miles, Sheet 15: 1912, also presented by the Director of H.M. Geological Survey.

December 18th, 1912.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

David Balsillie, B.Sc., Assistant in the Geological Department of University College, Dundee, 14 Greyfriars Garden, St. Andrews (Fifeshire); Robert Meldrum Craig, B.Sc., Assistant in the Geological Department of the University of St. Andrews, 3 Dempster Terrace, St. Andrews (Fifeshire); Godfrey Stephen Hart, Mount Morgan (Queensland); Ralph Hawtrey, Elizabeth College, Guernsey; Joseph Kelly, Seapark, Dollymount (County Dublin); Thomas Edward Nuttall, M.D., C.M., J.P., Middleton, Huncoat, Accrington;

Maurice Albion Ockenden, The Wigwam, Sanderstead (Surrey); Kiran Kumar Sengupta, M.A., B.Sc., Geologist to the Cochin State, Trichur, Cochin State (Southern India); Hugh Hamshaw Thomas, M.A., Curator of the Botanical Museum, Cambridge, 41 Owlstone Road, Cambridge; and James Mann Wordie, B.A., St. John's College, Cambridge, were elected Fellows of the Society.

Prof. Dr. Johannes Walther, Halle an der Saale, was elected a Foreign Member of the Society; Prof. Dr. Karl Diener, Vienna; Prof. Fusakichi Omori, Tokyo; and Prof. Dr. Ernst Weinschenk, Munich, were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'On the Discovery of a Palæolithic Human Skull and Mandible in a Flint-bearing Gravel overlying the Wealden (Hastings Beds) at Piltdown, Fletching (Sussex).' By Charles Dawson, F.S.A., F.G.S., and Arthur Smith Woodward, LL.D., F.R.S., F.L.S., Sec.G.S. With an Appendix by Prof. Grafton Elliot Smith, M.D., F.R.S.

The following specimens were exhibited:—

Specimens of flint-implements from Piltdown and other localities, exhibited by C. Dawson, F.S.A., F.G.S.; and skull and mandible from the Piltdown gravel-bed, with casts and restoration of the same, exhibited by Dr. Arthur Smith Woodward, F.R.S., F.L.S., Sec.G.S., in illustration of their paper.

Plaster casts of human and simian brain-cases, exhibited by Prof. G. Elliot Smith, M.D., F R.S.

Specimens of *Mastodon* from the Pliocene Cave, Doveholes (Derbyshire), exhibited by Prof. W. Boyd Dawkins, M.A., D.Sc., F.R.S., F.S.A., F.G.S.

January 8th, 1913.

Dr. Aubrey Strahan, F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following Fellows of the Society, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year: Henry A. Allen and Henry Dewey.

The following communications were read:—

1. 'The Geological History of the Malay Peninsula.' By John Brooke Scrivenor, M.A., F.G.S., Geologist to the Government of the Federated Malay States.

2. 'On a Mass of Anhydrite in the Magnesian Limestone at Hartlepool.' By Charles Taylor Trechmann, B.Sc. (Communicated by Prof. E. J. Garwood, M.A., V.P.G.S.)

The following specimens were exhibited:—

Fossils from the Malay Peninsula described by R. B. Newton, F.G.S., and others, collected and exhibited by J. B. Scrivenor, M.A., F.G.S., in illustration of his paper.

Specimens of anhydrite, etc., exhibited on behalf of C. T. Trechmann, B.Sc., in illustration of his paper.

January 22nd, 1913.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

Richard William Armitage, B.Sc., Inspector of Schools, Education Department, Melbourne (Victoria); Vincent Charles Illing, B.A., Chestnuts, Hartshill, near Atherstone (Warwickshire); Alister W. Jamieson, Colonel in H.M.'s Indian Army, 82 *a* Palmerston Road, Southsea; Herbert Harold Read, B.Sc., Assoc.R.C.S., 30 Church Road, Whitstable (Kent); Philip Alexander Satow, Assistant Warden in the Mines Department of the Federated Malay States, Batu Gajah (Perak); Leonard Frank Spath, B.Sc., 33 St. Clement's Mansions, Fulham, S.W.; and Talbot Haes Whitehead, B.Sc., 38 Coolhurst Road, Crouch End, N., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read;—

1. 'The Fossil Flora of the Cleveland District of Yorkshire: I—The Flora of the Marske Quarry.' By Hugh Hamshaw Thomas, M.A., F.G.S. With Notes on the Stratigraphy, by the Rev. George John Lane, F.G.S.

2. 'The Derived Cephalopoda of the Holderness Drift.' By Charles Thompson, B.Sc. (Communicated by G. W. Lamplugh, F.R.S., F.G.S.)

The following lantern-slides, specimens, photographs, etc., were exhibited:—

Lantern-slides of the plants from Marske Quarry, exhibited by H. Hamshaw Thomas, M.A., F.G.S., in illustration of his paper.

Specimens, photographs, and lantern-slides of derived cephalopoda from the Holderness Drift, exhibited on behalf of C. Thompson, B.Sc., in illustration of his paper.

A geological map of South Wales, with longitudinal sections across the coalfield, by E. E. L. Dixon, on the scale of 1 : 147,840, or 3 inches = 7 miles, presented by Messrs. George Philip & Son.

February 5th, 1913.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

Ben Ephraim Lamartine Culpin, The Lodge, Valentines, Ilford (Essex); Ernest Gibson, F.L.S., 25 Cadogan Place, S.W.; T. Wilson Parry, M.A., M.D., Belmont, Crouch-End Hill, N.; and William C. Simmons, B.Sc., Assoc.R.C.S., 28 Jermyn Street, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On Two Deep Borings at Calvert Station (North Buckinghamshire), and on the Palæozoic Floor north of the Thames.' By Arthur Morley Davies, A.R.C.S., D.Sc., F.G.S., and John Pringle, H.M. Geological Survey.

2. On the Skeleton of *Ornithodesmus latidens*, an Ornithosaur from the Wealden Shales of Atherfield (Isle of Wight).' By Reginald Walter Hooley, F.G.S.

Specimens, microscope-sections, and lantern-slides were exhibited by Dr. A. Morley Davies, F.G.S., in illustration of his and Mr. Pringle's paper. Specimens from the Calvert Boring were also exhibited by the Director of H.M. Geological Survey.

ANNUAL GENERAL MEETING,

February 21st, 1913.

Dr. Aubrey Strahan, F.R.S., President.
in the Chair.

Report of the Council for 1912.

During the year under review 63 new Fellows were elected into the Society, 15 more than during 1911. Of the 63 Fellows elected in 1912, 44 paid their Admission Fees before the end of that year. Of the Fellows who had been elected in the previous year, 13 paid their Admission Fees in 1912, making the total accession of new Fellows during the year under review amount to 57 (10 more than in 1911).

Deducting from this number a loss of 52 Fellows (1 elected Foreign Correspondent, 15 resigned, 28 deceased, and 8 removed from the List, under Bye-Laws, Sect. VI, Art. 5), it will be seen that there is an increase of 5 in the Number of Fellows (as compared with a decrease of 5 in 1911 and an increase of 5 in 1910).

The total Number of Fellows is, therefore, now 1299, made up as follows:—Compounders, 247 (one less than in 1911); Contributing Fellows, 1031 (7 more than in 1911); and Non-contributing Fellows, 21 (1 less than in 1911).

Turning to the Lists of Foreign Members and Foreign Correspondents, the Council recall with regret the loss during the past year of Prof. G. J. Brush and Prof. F. Zirkel, Foreign Members; as also of Prof. F. A. Forel, Prof. E. von Koken, Prof. C. de Kroustchoff, and Prof. R. S. Tarr, Foreign Correspondents. The vacancies in the List of Foreign Members were filled by the election of Prof. M. Boule and Prof. J. Walther. It will be remembered that there were three vacancies in the List of Foreign Correspondents at the end of 1911. These were filled by the election of Dr. F. W. Clarke, Dr. Whitman Cross, and Baron F. Nopcsa. Three further vacancies were filled by the election of Prof. C. Diener, Dr. F. Omori, and Prof. E. Weinschenk, but there still remain three vacancies in the List of Foreign Correspondents.

With regard to the Income and Expenditure of the Society during 1912, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—The actual Receipts (excluding the Balance of £475 11*s.* 10*d.* brought forward from the previous year) amounted to £3417 15*s.* 9*d.*, being £367 9*s.* 9*d.* more than the estimated Income. On the other hand, the total Expenditure during the

same year amounted to £3252 5*s.* 6*d.*, being £222 7*s.* 6*d.* more than the estimated Expenditure for the same year, and £165 10*s.* 3*d.* less than the actual Receipts, the year closing with a Balance in hand of £641 2*s.* 3*d.*

The Council have to announce the completion of Vol. LXVIII of the Society's Journal, as also the publication of No. 18 of the List of Geological Literature. The Central Bureau of the International Catalogue of Scientific Literature has now accepted this List as the basis of the 'British Geology' Section of that Catalogue.

A successful and largely attended Conversazione was held in the Society's Apartments on June 26th, 1912. During the past year those Apartments have been used for General or for Council Meetings by the Mineralogical Society, the Palæontographical Society, the Ray Society, the Geologists' Association, the Institution of Mining & Metallurgy, the Institution of Mining Engineers, the Institution of Water Engineers, and the British Science Guild.

Improvements have been effected in the electric lighting arrangements in the Meeting Room, and the movable table which formerly stood on the Presidential dais has been replaced by a rostrum of oak, constructed under the supervision of H.M. Office of Works. During the celebration of the 250th Anniversary of the Royal Society, the Meeting Room was made available as a Post Office and Information Bureau & Writing Room for the use of the Delegates who attended that celebration.

Mr. Clyde H. Black resigned the Assistant Clerkship, on the ground of ill-health, on March 13th, 1912; and, on May 15th, the Council temporarily appointed Mr. Maurice St. John Hope to fill the vacancy thus created, subject to confirmation by the Fellows at a Special General Meeting.

Reports have now been received from the two Museums to which the Society's collections were transferred in 1911.

The Director of the British Museum (Natural History) reports as follows:—

The collection of foreign and colonial fossils, minerals, and rock-specimens was removed to the British Museum (Natural History) in June 1911, and at once transferred to suitable cabinets.

Fossils.

A range of cabinets containing 750 glazed, dust-proof drawers, in one of the work-rooms of the Department of Geology, had been specially prepared for the reception of the smaller fossils which had occupied drawers in the Geological Society's Museum. The fossils were arranged in geographical order, drawer by drawer, exactly as in the Society's Museum, so that the original MS. list, which was copied, could still be used as an index to the collection. The fossils thus remained inaccessible only for the few days during their removal, and the improved accommodation soon made it possible to refer to them with ease. When the drawers had been labelled, the work of cleaning the collection, mending broken specimens, and collating displaced labels was systematically begun; and, during subsequent months, much progress has been made in putting the drawers in good order, with new trays, tubes, and glass-topped boxes for all specimens which seemed to need such protection.

Sufficient printed labels have been prepared to mark each specimen presented by the Geological Society, and it is proposed not to incorporate any of the contents of the drawers with the general collection of the Museum until the whole have been thoroughly curated, registered, and studied.

The larger foreign fossils which occupied shelves and cupboards in the Society's Museum, were cleaned and sorted as soon as received, and temporarily arranged in groups in dust-proof glazed cases in a basement work-room. The preparation of suitable fittings and mounts for these large specimens will occupy considerable time, but a beginning has been made, and all the more important fossils registered in the Society's Catalogue will soon be incorporated in the exhibited series of the Museum, each with an appropriate printed label. The Siwalik Mammalia, especially, and some other Proboscidean remains, will form an important addition to this collection.

With the sanction of the Council of the Geological Society, the Trustees of the British Museum have made two gifts of duplicates from the collection. They have presented a series of recent shells to the National Museum for Wales, Cardiff, and a plaster cast of *Mosasaurus hoffmanni* to the Norwich Castle Museum. These appear to be all the duplicates in the collection available for distribution.

A. SMITH WOODWARD, *Keeper of Geology.*

Minerals and Rock-Specimens.

The large series of foreign minerals and rocks has been arranged in drawers in a room in the south-eastern basement of the Museum, where it is now available for study.

Of the minerals, those which have been described and figured, or are exceptionally well-crystallized or rare, have been registered and incorporated in the General Collection. These include a fine series of rubies in the matrix, from the Burma Ruby-Mines, described by Prof. Judd, in 1888; remarkable crystals of columbite from Greenland, presented by John Taylor; nuggets of gold and platinum, presented by Baron A. von Meyendorf about 1842; and various interesting and rare minerals presented by G. B. Greenough, Henry Holdsworth, Henry Heuland, and H. J. Brooke.

The rest of the mineral specimens will be useful as the nucleus of a series available for students, and for this purpose a special cabinet has been provided.

By far the larger part of the collections transferred from the Geological Society consists of rock-specimens, of which there are about 17,000, belonging to some 400 different topographical collections, besides a series arranged according to species.

The species collection, as in the case of the minerals, will be useful as a series available for students, and for this also a special cabinet has been provided.

The topographical collections have been arranged in accordance with the geographical scheme used in the International Catalogue of Scientific Literature. They will be very useful in filling gaps in the large series of foreign rocks already in the Museum. At present, however, they are kept apart from the main collection of rocks until the work of examination and comparison has been completed. In the course of this work some removal of duplicates may prove to be necessary, since in past years duplicates from the Geological Society's Museum were occasionally presented to the British Museum. In all probability, however, most of the material not required for the Museum will consist of badly localized and unlabelled specimens, the presentation of which to other institutions would be useless.

Some of the topographical collections were brought together by such eminent pioneers in the study of geology as Lyell, Scrope, De la Beche, and Murchison, and are therefore of considerable historic interest. On this account, such collections have been sorted out and carefully separated, when, as was found to be the case for certain districts, the specimens belonging to several of these collections had been mixed.

Of these older collections the following may be mentioned :—the specimens from the Faröe Islands described in 1821 by W. C. Trevelyan; a collection from Normandy described in 1824 by De la Beche; the large series from Auvergne collected and described by Scrope in 1827; another collection from the same region collected and described by Lyell & Murchison in 1828; the collections from Italian volcanic districts made by Scrope in 1823–24; a series from Greenland collected by Giesecke; and various collections from India described in papers in the Quarterly Journal.

It is a subject of congratulation to the Museum that old collections of rocks of such historic interest should have finally found their resting place in the National Collection.

G. T. PRIOR, *Keeper of Minerals.*
L. FLETCHER, *Director.*

The Director of the Museum of Practical Geology reports as follows :—

The whole of this large collection was transferred to cabinets during the late summer and autumn months of 1911, and the Society's drawers were subsequently delivered to the purchasers.

Fossils.

During the process of transference to the storage-cabinets, the specimens were made as clean as possible, and were then so arranged that they became readily accessible for purposes of study. Only some dozen or so of the great number of fossils recorded in the Society's catalogues have not yet been traced.

Nearly a thousand tablets of specimens have been placed on exhibition in the Museum in their respective stratigraphical positions, each bearing a distinctive label :—'Geol. Society Coll.' Further material is being drafted into the Museum as opportunity permits.

In that part of the collection which was registered by Mr. C. D. Sherborn and recorded in the late Prof. J. F. Blake's valuable Catalogue, the specimens can always be referred to by means of their original register-numbers. All these will be kept permanently. The remainder, amounting to considerably more than three-quarters of the whole, is being examined critically and in large part registered, a work which will necessarily occupy much time. Most of the material is of high quality, so that it may be anticipated that a relatively small proportion of it will have to be discarded and set aside for donation to other institutions. During the process of sorting out and registering that greater part which it is intended to keep permanently, comparison has to be made with the collections already displayed or stored at Jermyn Street, in order to ascertain what portions of the new collection are supplementary to these, and what material can be considered to represent duplicates in the strict sense. A careful watch is also being kept for any specimens, in addition to those previously recognized, which may have been mentioned in publications. A few have already been detected, including some that have been figured. The fact that such specimens are not mentioned in the Catalogues of Mr. Sherborn and the late J. F. Blake must not be taken to imply that the work of those recorders was wanting in thoroughness or discrimination; it has been found that the manuscript catalogue and the published catalogue are both remarkable for their degree of completeness and accuracy.

While, for the above reasons, it is impossible to hasten the process whereby this extensive collection is being made to take final shape, the specimens are being maintained in good order, and in the meantime are available for general reference.

Rock-Specimens.

The collection of British rocks consisted of two portions: a larger portion of about 3000 specimens, which formed part of the Society's registered collection; and about eighty drawers full of unregistered material. Except in a few instances, it has been possible to trace all the registered specimens as mentioned in the Society's catalogue.

The whole collection has been cleaned, and the registered portion carefully stored in a manner which renders it easily available for reference.

In the Society's rooms the rocks were arranged as far as possible according to age, but this often meant that a collection originally intended by the donor to illustrate some particular geological principle or district was divided into several parts. Owing to the fact that the historical interest attached to these rocks often outweighs their value as museum-specimens, those collected by an author for a special purpose have been brought together; and thus those suites of specimens which illustrate papers in the Society's or other publications have been arranged as separate units.

With reference to the Society's request that any material which the Museum does not wish to retain permanently should be specified, it may be stated that all that portion of the Society's collection which bears registration-numbers will be retained; and that, owing to the excellent manner in which the original registration was carried out, re-registration will not be necessary.

About seventeen drawers full of unregistered specimens have been considered of sufficient value and interest to merit their incorporation with the Museum collection, and a catalogue of these specimens is in the course of construction. As the work of examining the remainder of the unregistered material progresses there will be doubtless many more specimens which will find a place in the collection; but, until the examination is more nearly complete, it will be impossible to say how much material will be available for distribution to other institutions.

Minerals.

The mineral specimens received from the Geological Society, about twenty in number, have been registered and placed partly in the mineral store and partly in exhibition-cases; all are available for reference.

A few specimens are being kept for consideration as regards their ultimate destination.

In concluding this report, it is a pleasant duty to lay emphasis on the great value and importance of this large collection. The fossils, in particular, may be said to constitute one of the finest acquisitions to the Museum of Practical Geology that this institution has ever received.

J. J. H. TEALL, *Director.*

The tenth Award from the Daniel Pidgeon Trust Fund was made on April 17th, 1912, to Otway H. Little, M.A., Royal College of Science for Ireland, who proposed to investigate the chemical and mineral changes which have taken place in the metamorphic limestone of Connemara. A preliminary report on the progress of the investigation has been received from Mr. Little, who has now joined the staff of the Egyptian Geological Survey.

The following Awards of Medals and Funds have also been made by the Council:—

The Wollaston Medal is awarded to the Rev. Osmond Fisher, M.A., in recognition of his 'researches concerning the Mineral

Structure of the Earth,' especially in connexion with the physics of the earth's crust.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Mr. George Barrow, in recognition of his valuable contributions to Geological Science, more especially in connexion with the problems of the Scottish Highlands.

The Lyell Medal, together with a sum of Forty Pounds from the Lyell Geological Fund, is awarded to Mr. S. S. Buckman, as an acknowledgment of the value of his contributions to our knowledge of Jurassic Geology and the classification of Ammonites and Brachiopoda.

The Bigsby Medal is awarded to Sir Thomas Henry Holland, K.C.I.E., in recognition of the value of his contributions to our knowledge of the Geology of India, and to encourage him in further research.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. William Wickham King, in recognition of the value of his researches among the Palæozoic rocks of the Midlands.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. Ernest Edward Leslie Dixon, B.Sc., in acknowledgment of his researches among the Carboniferous rocks.

The Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Llewellyn Treacher, in recognition of the value of his contributions to our knowledge of the Cretaceous formations of the South of England.

A moiety of the Balance of the Proceeds of the Barlow-Jameson Fund is awarded to John Brooke Scrivenor, M.A., in acknowledgment of his researches on the Geology of the Malay Peninsula.

A second moiety of the Balance of the Proceeds of the Barlow-Jameson Fund is awarded to Bernard Smith, M.A., in recognition of the value of his researches among the Triassic rocks of the Midlands, and the Glacial deposits of the southern portion of the Lake District.

Report of the Library Committee for 1912.

The Committee have pleasure in stating that the Additions made to the Society's Library during the past year have fully maintained, both in number and in importance, the standard of previous years.

During 1912 the Library received by Donation 262 Volumes of separately published Works, 390 Pamphlets, and 34 detached

Parts of Works; as also 431 Volumes and 69 detached Parts of Serial Publications, and 16 Volumes of Weekly Periodicals.

The total number of accessions to the Library by Donation is thus seen to amount to 709 Volumes, 390 Pamphlets, and 103 detached Parts. No less than 101 Sheets of Geological Maps were presented to the Library, including 27 Sheets received from the Geological Survey of England & Wales, and 8 Sheets from that of Scotland; 9 Folios of the Geologic Atlas of the United States; 13 Sheets received from the Geological Survey of Japan; 5 Sheets from the Swiss Geological Commission; 6 Sheets from the Geological Commission of the Cape of Good Hope; 4 Sheets from the Austro-Hungarian Geological Survey; 4 Sheets of the Russian Government's Geological Map of the Donetz Basin; and 3 Sheets received from the Geological Survey of Canada.

Among the Books and Pamphlets mentioned in the foregoing paragraph especial attention may perhaps be directed to the following works: Prof. T. G. Bonney's 'Building of the Alps'; Mr. H. B. Woodward's 'Geology of Soils & Substrata'; the 4th edition of Dr. E. Kayser's 'Textbook of Geology,' Part I; Dr. L. Carez's 'Summary of the Geology of the French Pyrenees'; Prof. Vinassa de Regny's monograph on Italy's new North African Colony, entitled 'Libya italica'; M. L. Gentil's 'Le Maroc physique'; Prof. E. H. L. Schwarz's 'South African Geology'; Mr. W. E. Ford's new edition of Dana's 'Manual of Mineralogy'; the fourth edition of Dr. F. H. Hatch's 'Textbook of Mineralogy'; the memoir on the Geology of the Bergen District by Prof. C. F. Kolderup & Mr. H. W. Monckton; Prof. R. Munro's 'Palæolithic Man & Terramara Settlements in Europe'; Mr. L. Richardson's 'Geology of Cheltenham'; Dr. R. F. Scharff's 'Distribution & Origin of Life in America'; the British Museum (Natural History) Guide to the Collection of Animals, Plants, & Minerals mentioned in the Bible; also Mr. W. F. P. McLintock's Guide to the Collection of Gem Stones in the Museum of Practical Geology; the Geological Survey memoirs on the Geology of the Country around Cardiff (2nd edition), on the Geology of the Country around Tavistock & Launceston, on the Mesozoic Rocks found in some of the Coal-Explorations in Kent, on the Water-Supply of Surrey, on the Geology of the Lizard & Meneage, on the Geology of the Country around Ollerton, on the Geology of Knapdale, Jura & North Kintyre, on the Geology of Braemar, Ballater, & Glen Clova, on the Interbasaltic Rocks of North-East Ireland, and on the British Carboniferous Trepostomata. M. H. de Dorlodot sent a collection of seventeen of his recent papers on Belgian Palæozoic geology; and the 3rd edition (1912) of the late Rev. R. A. Bullen's monograph on the Harlyn Bay Prehistoric Site was also received. In addition, numerous publications were received from the Departments of Mines and Geological Survey Departments of Canada, New South Wales, New Zealand, Tasmania, the Union of South Africa (Cape of Good Hope and the Transvaal), Egypt, and the Anglo-Egyptian Sudan; from the United States Geological Survey, and from the

independent State Surveys of Connecticut, Maryland, and Washington; also from the Geological Survey departments of India, Mysore, Finland, Italy, the Netherlands, Portugal, Russia, and Switzerland. Prof. J. Milne's Catalogue of Earthquakes to 1911, and Dr. C. Davison's work on the Origin of Earthquakes were the chief seismological publications received.

The Books and Maps enumerated in the foregoing paragraphs were the gift of 162 Government Departments and other Public Bodies; of 185 Societies and Editors of Periodicals; and of 155 Personal Donors.

The Purchases, made on the recommendation of the standing Library Committee, included 38 Volumes and 12 detached Parts of separately published Works; 86 Volumes and 18 detached Parts of Works published serially; and 8 Sheets of Geological Maps.

A portion of the Proceeds of the Prestwich Fund set aside for the special purpose of the Society's Library was spent in 1912.

The Expenditure upon the Library (apart from the cost of refitting the old Museum Cabinets to take the new Bookshelves, etc.) during the year under review was as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased	84	9	7
Binding of Books and Mounting of Maps ..	142	10	4
Lettering of new Bookshelves	11	12	10
Total..........	£238	12	9

Mr. C. Davies Sherborn reports that 'the Card Catalogue continues to make satisfactory progress.'

The congestion in the Lower Library has been relieved by the removal of several thousand volumes upstairs to the new Library Extension which occupies the space formerly taken up by the Society's Museum. The re-arrangement of the books in the ground-floor Library will follow in due course. In the Library Extension an endeavour has been made to follow as far as possible a geographical arrangement of the serials.

The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review :—

I. Government Departments and other Public Bodies.

Alabama.—Geological Survey. Montgomery (Ala.).
American Museum of Natural History. New York.
Anglo-Egyptian Sudan.—Geological Survey. Khartum.
Argentina.—Ministerio de Agricultura. Buenos Aires.
Australia (S.), etc. *See* South Australia, *etc.*
Austria.—Kaiserlich-Königliche Geologische Reichsanstalt. Vienna.
Bavaria.—Königliches Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique, Brussels.
——. Musée du Congo Belge. Brussels.
——. Musée Royal d'Histoire Naturelle. Brussels.
——. Service Géologique de Belgique. Brussels.
Bergens Museum. Bergen.
Berlin.—Königliche Preussische Akademie der Wissenschaften.
Birmingham, University of.
Bohemia.—Naturwissenschaftliche Landesdurchforschung. Prague.
——. Royal Museum of Natural History. Prague.
Bristol.—Museum & Art Gallery.
——. Public Library.
British Columbia.—Department of Mines. Victoria (B.C.).
British Guiana.—Department of Mines. Georgetown.
British South Africa Company. London.
Bucarest.—Museului de Geologia si de Paleontologia.
Buenos Aires.—Museo Nacional de Buenos Aires.
California.—Academy of Sciences. San Francisco.
——, University of. Berkeley (Cal.).
Camborne.—Mining School.
Cambridge (Mass.).—Museum of Comparative Zoology in Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
——, High Commissioner for. London.
Cape of Good Hope.—Department of Agriculture (Geological Commission). Cape Town.
——. South African Museum. Cape Town.
Chicago.—'Field' Columbian Museum.
Connecticut.—State Geological & Natural History Survey. Hartford (Conn.).
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Cracow.—Academy of Sciences.
Denmark.—Commission for Ledelsen af de Geologiske & Geographiske Undersögelser i Grönland. Copenhagen.
——. Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works (Survey Department). Cairo.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère de la Guerre. Paris.
——. Ministère des Colonies. Paris.
——. Ministère des Travaux Publics. Paris.
——. Muséum d'Histoire Naturelle. Paris.
Geneva, University of.
Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle an der Saale.
Great Britain.—Army Medical Department. London.
——. British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. India Office. London.

Holland.—Departement van Kolonien. The Hague.
——. Rijksopsporing van Delfstoffen. The Hague.
Hull.—Municipal Museum.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
Illinois State Geological Survey. Urbana (Ill.).
India.—Geological Survey. Calcutta.
——. Indian Museum. Calcutta.
——. Surveyor-General's Office. Calcutta.
Iowa Geological Survey. Des Moines (Iowa).
Ireland.—Department of Agriculture & Technical Instruction. Dublin.
Italy.—Reale Comitato Geologico. Rome.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
Jassy, University of.
Kansas.—University Geological Survey. Lawrence (Kan.).
Kingston (Canada).—Queen's College.
Klausenburg (Koloszvár).—Provincial Museum & Library.
Leeds, University of.
London.—City of London College.
——. Imperial College of Science & Technology.
——. Imperial Institute.
——. Royal College of Surgeons.
——. University College.
Madrid.—Real Academía de Ciencias Exactas, Físicas & Naturales.
Magdeburg.—Museum für Natur- und Heimatkunde.
Maryland.—Geological Survey. Baltimore (Md.).
Melbourne (Victoria).—National Museum.
Mexico.—Instituto Geológico. Mexico City.
Michigan College of Mines. Houghton (Mich.).
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Missouri.—Bureau of Geology & Mines. Rolla (Mo.).
Montana University. Missoula (Mont.).
Munich.—Königliche Bayerische Akademie der Wissenschaften.
Mysore Geological Department. Bangalore.
Nancy.—Académie de Stanislas.
Naples.—Accademia delle Scienze.
Natal.—Department of Mines. Pietermaritzburg.
——. Geological Survey. Pietermaritzburg.
——. Government Museum. Pietermaritzburg.
New Jersey.—Geological Survey. Trentham (N.J.).
New Mexico, University of. Albuquerque (N. Mex.).
New South Wales, Agent-General for. London.
——. Department of Mines & Agriculture. Sydney.
——. Geological Survey. Sydney.
New York State Museum. Albany (N.Y.).
New Zealand.—Department of Mines. Wellington.
——. Geological Survey. Wellington.
Norway.—Norges Geologiske Undersökelse. Christiania.
Nova Scotia.—Department of Mines. Halifax.
Ohio Geological Survey. Columbus (Ohio).
Oklahoma Geological Survey. Norman (Okla.).
Ontario.—Bureau of Mines. Toronto.
Padua.—Reale Accademia di Scienze, Lettere & Arti.
——. University.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Peru.—Ministerio de Fomento. Lima.
Philippine Is.—Department of the Interior: Bureau of Science. Manila.
Pisa, Royal University of.
Portici.—Reale Scuola Superiore di Agricoltura.
Portugal.—Commissão dos Trabalhos Geologicos. Lisbon.
Prussia.—Königliches Ministerium für Handel & Gewerbe. Berlin.
——. Königliche Preussische Geologische Landesanstalt. Berlin.
Queensland, Agent-General for. London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.

Redruth.—School of Mines.
Rhodesia.—Chamber of Mines. Bulawayo.
Rhodesian Museum. Bulawayo.
Rio de Janeiro.—Museu Nacional.
Rome.—Reale Accademia dei Lincei.
Rumania.—Geological Survey. Bucarest.
Russia.—Comité Géologique. St. Petersburg.
——. Musée Géologique Pierre le Grand. St. Petersburg.
——. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
São Paulo (Brazil).—Commissão Geographica & Geologica. São Paulo City.
——. Secretaria da Agricultura, Commercio & Obras Publicas. São Paulo City.
Sarawak Museum. Singapore.
South Africa.—Department of Mines of the Cape of Good Hope.
South Australia, Agent-General for. London.
——. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Spain.—Comision del Mapa Geológico. Madrid.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
Tohoku.—Imperial University.
Tokio.—College of Science.
Transvaal.—Geological Survey. Pretoria.
——. Mines Department. Pretoria.
Transylvania.—National Museum: Geological & Mineralogical Department. Hermannstadt.
Turin.—Reale Accademia delle Scienze.
United States.—Department of Agriculture. Washington (D.C.).
——. Geological Survey. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala, Royal University of.
Victoria (Austral.), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
—— (——). Geological Survey. Melbourne.
Vienna.—Kaiserliche Akademie der Wissenschaften.
Washington (D.C.).—Smithsonian Institution.
Washington, State of (U.S.A.).—Geological Survey. Olympic (Wash.).
West Indies.—Imperial Agricultural Department. Bridgetown (Barbados).
Western Australia, Agent-General for. London.
——. Department of Mines. Perth.
——. Geological Survey. Perth.
——. Museum & Art Gallery. Perth.
Wisconsin.—Geological & Natural History Survey. Madison (Wisc.).
Yale University Museum (Peabody Museum). Geological Department. New Haven (Conn.).

II. Societies and Editors.

Acireale.—Accademia di Scienze, Lettere & Arti.
Adelaide.—Royal Society of South Australia.
Agram.—Societas Historico-Naturalis Croatica.
Alnwick.—Berwickshire Naturalists' Club.
Aylesbury.—Architectural & Archæological Society for the County of Buckingham.
Basel.—Naturforschende Gesellschaft.
Bath.—Natural History & Antiquarian Field-Club.
Belgrade.—Servian Geological Society.
Bergen.—'Naturen.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. Institut für Meereskunde & Geographisches Institut.
——. 'Zeitschrift für Praktische Geologie.'
Berne.—Schweizerische Naturforschende Gesellschaft.

Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston (Mass.) Society of Natural History.
——. American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Brooklyn (N.Y.) Institute of Arts & Sciences.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société Belge de Géologie, de Paléontologie & d'Hydrologie.
——. Société Royale Zoologique & Malacologique de Belgique.
Budapest.—Földtani Közlöny.
Buenos Aires.—Sociedad Científica Argentina.
Bulawayo.—Rhodesian Scientific Association.
Caen.—Société Linnéenne de Normandie.
Calcutta.—Asiatic Society of Bengal.
——. 'Indian Engineering.'
Cambridge Philosophical Society.
Cape Town.—Royal Society of South Africa.
——. South African Association for the Advancement of Science.
——. South African Philosophical Society.
Cardiff.—South Wales Institute of Engineers.
Chambéry.—Société d'Histoire Naturelle de Savoie.
Chicago.—'Journal of Geology.'
Christiania.—'Nyt Magazin for Naturvidenskaberne.'
Colombo.—Ceylon Branch of the Royal Asiatic Society.
Colorado Springs.—'Colorado College Studies.'
Croydon Natural History & Scientific Society.
Denver.—Colorado Scientific Society.
Dijon.—Académie des Sciences, Arts & Belles-Lettres.
Dorchester.—Dorset Natural History & Antiquarian Field-Club.
Dorpat (Jurjew).—Naturforschende Gesellschaft.
Dresden.—Naturwissenschaftliche Gesellschaft.
——. Verein für Erdkunde.
Edinburgh.—Geological Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Falmouth.—Royal Cornwall Polytechnic Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Fribourg.—Société Fribourgeoise des Sciences Naturelles.
Geneva.—Société de Physique & d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.
Gratz.—Naturwissenschaftlicher Verein für Steiermark.
Haarlem.—Société Hollandaise des Sciences.
Halifax (N.S.).—Nova Scotian Institute of Science.
Hamilton (Canada).—Hamilton Scientific Association.
Hanau.—Wetterauische Gesellschaft für Gesammte Naturkunde.
Havre.—Société Géologique de Normandie.
Helsingfors.—Société Géographique de Finlande.
Hereford.—Woolhope Naturalists' Field-Club.
Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaft.
Hertford.—Hertfordshire Natural History Society.
Hull Geological Society.
Indianapolis (Ind.).—Indiana Academy of Science.
Johannesburg.—Geological Society of South Africa.
Kiev.—Société des Naturalistes.
Lancaster (Pa.).—'Economic Geology.'
Lausanne.—Société Vaudoise des Sciences Naturelles.
Leeds.—Philosophical & Literary Society.
——. Yorkshire Geological Society.
Leicester Literary & Philosophical Society.
Leipzig.—'Zeitschrift für Krystallographie & Mineralogie.'
Liége.—Société Géologique de Belgique.
——. Société Royale des Sciences.
Lille.—Société Géologique du Nord.

Lima.—'Revista de Ciencias.'
Lisbon.—Sociedade de Geographia.
——. Société Portugaise des Sciences Naturelles.
Liverpool Geological Society.
——. Literary & Philosophical Society.
London.—'The Athenæum.'
——. British Association for the Advancement of Science.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Institution of Water Engineers.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Journal.'
——. 'Nature.'
——. Palæontographical Society.
——. 'The Quarry.'
——. Ray Society.
——. 'Records of the London & West-Country Chamber of Mines.
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. Society of Biblical Archæology.
——. 'The South-Eastern Naturalist' (S.E. Union of Scientific Societies).
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester Geological & Mining Society.
——. Literary & Philosophical Society.
Manila.—'Philippine Journal of Science.'
Melbourne (Victoria).—Australasian Institute of Mining Engineers.
——. Royal Society of Victoria.
——. 'The Victorian Naturalist.'
Mexico.—Sociedad Científica 'Antonio Alzate.'
Moscow.—Société Impériale des Naturalistes.
Newcastle-upon-Tyne.—North of England Institute of Mining & Mechanical Engineers.
——. University of Durham Philosophical Society.
New Haven (Conn.).—Academy of Arts & Sciences.
——. 'The American Journal of Science.'
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. 'Science.'
Northampton.—Northamptonshire Natural History Society.
Nürnberg.—Naturhistorische Gesellschaft.
Oporto.—Academia Polytecnica. [Coimbra.]
Ottawa.—Royal Society of Canada.
Paris.—Commission Française des Glaciers.
——. Société Française de Minéralogie.
——. Société Géologique de France.
——. 'Spelunca.'
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Pisa.—Società Toscana di Scienze Naturali.

Plymouth.—Devonshire Association for the Advancement of Science.
Portland Society of Natural History. Portland (Maine).
Rennes.—Société Scientifique & Médicale de l'Ouest.
Rochester (N.Y.).—Academy of Science.
——. Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
San Diego (Cal.).—Society of Natural History.
Santiago de Chile.—Sociedad Nacional de Minería.
——. Société Scientifique du Chili.
São Paulo (Brazil).—Sociedade Scientifica.
Scranton (Pa.).—'Mines & Minerals.'
St. John (N.B.).—Natural History Society of New Brunswick.
St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Stuttgart.—'Centralblatt für Mineralogie, Geologie & Paläontologie.'
——. 'Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.'
——. Oberrheinischer Geologischer Verein.
——. Verein für Vaterländische Naturkunde in Württemberg.
——. 'Zeitschrift für Naturwissenschaften.'
Swansea.—Royal Institution of South Wales.
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Truro.—Royal Institution of Cornwall.
Upsala.—Geological Institution of the University.
Vienna.—'Beiträge zur Paläontologie & Geologie Œsterreich-Ungarns & des Orients.'
——. 'Berg- & Hüttenmännisches Jahrbuch.'
——. Geologische Gesellschaft.
——. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Philosophical Society.
Wellington (N.Z.).—New Zealand Institute.
Wiesbaden.—Nassauischer Verein für Naturkunde.
Worcester.—Worcestershire Naturalists' Club.
York.—Yorkshire Philosophical Society.

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Woodward, Henry.
Woodward, H. B.

Zeiller, R.

Comparative Statement of the Number of the Society at the Close of the Years 1911 and 1912.

	Dec. 31st, 1911.		Dec. 31st, 1912.
Compounders	248	......	247
Contributing Fellows......	1024	......	1031
Non-Contributing Fellows..	22	......	21
	1294		1299
Foreign Members	40	......	40
Foreign Correspondents....	37	......	37
	1371		1376

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1911 and 1912.

Number of Compounders, Contributing and Non-Contributing Fellows, December 31st, 1911 ..		1294
Add Fellows elected during the former year and paid in 1912		13
Add Fellows elected and paid in 1912		44
		1351
Deduct Compounders deceased................	7	
Non-Contributing Fellow deceased	1	
Contributing Fellows deceased	20	
Contributing Fellows resigned	15	
Contributing Fellow elected Foreign Correspondent	1	
Contributing Fellows removed	8	
	—	52
		1299
Number of Foreign Members and Foreign Correspondents, December 31st, 1911..........	77	
Deduct Foreign Members (2) and Foreign Correspondents (4) deceased; also Foreign Correspondents elected Foreign Members (2)	8	
	69	
Add Foreign Members elected	2	
Add Foreign Correspondents elected	6	
	—	77
		1376

Deceased Fellows.

Compounders (7).

Attwood, G.
Bullen, Rev. R. A.
Burton, F. M.
Maw, G.
Phené, Dr. J. S.
Whitehead, Sir Charles.
Worms, Baron de.

Non-contributing Fellow (1).

Dickinson, J.

Resident and other Contributing Fellows (20).

Bisset, J.
Blaikie, J.
Enys, J. D.
Eunson, J.
Fauvel, C. J.
Fidler, H.
Haines, J. R.
Higson, J.
Hobson, Maj.-Gen. F. T.
Morison, Dr. J.
Nevin, J.
Newbitt, T.
Parker, J.
Paul, J. D.
Pickering, W. H.
Stiffe, Capt. A. W.
Traquair, Dr. R. H.
Wall, G. P.
West, C. O.
Whiteside, R. F.

Fellows Resigned (15).

Andrews, E.
Berrington, R. E. W.
Cooke, Capt. J. H.
Cox, Prof. S. H.
Davis, A. R. V.
Drew, J.
Eddy, J. R.
Evans, I. V.
Fowler, T. W.
James, A.
Lemon, Sir James.
Marston, W. H.
Read, E. W.
Robinson, H.
Sanders, Rev. S. J. W.

Fellow elected Foreign Correspondent.

Cross, Dr. Whitman.

Fellows Removed (8).

Armstrong, W., jun.
Davey, T. G.
Jackson, C. F. V.
Johnson, R. S.
Knight, Capt. J. M.
Laffan, G. B.
Spencer, J. H.
Webb, C. F.

The following Personages were elected Foreign Members during the year 1912:—

Prof. Marcellin Boule, of Paris.

Prof. Dr. Johannes Walther, of Halle an der Saale.

The following Personages were elected Foreign Correspondents during the year 1912:—

Dr. Frank Wigglesworth Clarke, of Washington, D.C.

Dr. Whitman Cross, of Washington, D.C.

Baron Ferencz Nopcsa, of Schloss Ujarad, Temesmegye.

Prof. Dr. Karl Diener, of Vienna.

Prof. Fusakichi Omori, of Tokyo.

Prof. Dr. Ernst Weinschenk, of Munich.

After the Reports had been read, it was resolved:—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved:—

That the thanks of the Society be given to Dr. J. E. Marr, the retiring Vice-President (retiring also from the Council), and to the other retiring Members of Council: Dr. Tempest Anderson, Dr. C. W. Andrews, Prof. W. S. Boulton, and Mr. R. S. Herries.

After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

OFFICERS AND COUNCIL.—1913.

PRESIDENT.

Aubrey Strahan, Sc.D., F.R.S.

VICE-PRESIDENTS.

Prof. Edmund Johnston Garwood, M.A.
Richard Dixon Oldham, F.R.S.
Clement Reid, F.R.S., F.L.S.
Prof. William Whitehead Watts, LL.D., Sc.D., M.Sc., F.R.S.

SECRETARIES.

Arthur Smith Woodward, LL.D., F.R.S., F.L.S.
Herbert Henry Thomas, M.A., B.Sc.

FOREIGN SECRETARY.

Sir Archibald Geikie, K.C.B., D.C.L., LL.D., Sc.D., Pres.R.S.

TREASURER.

Bedford McNeill, Assoc.R.S.M.

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Richard Dixon Oldham, F.R.S.
George Thurland Prior, M.A., D.Sc., F.R.S.
Clement Reid, F.R.S., F.L.S.
Aubrey Strahan, Sc.D., F.R.S.
Herbert Henry Thomas, M.A., B.Sc.
Arthur Vaughan, M.A., D.Sc.
Prof. William Whitehead Watts, LL.D., Sc.D., M.Sc., F.R.S.
William Whitaker, B.A., F.R.S.
Rev. Henry Hoyte Winwood, M.A.
Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1912.

Date of Election.

1877. Prof. Eduard Suess, *Vienna.*
1880. Geheimrath Prof. Ferdinand Zirkel, *Leipzig.* (*Deceased.*)
1884. Commendatore Prof. Giovanni Capellini, *Bologna.*
1885. Prof. Jules Gosselet, *Lille.*
1886. Prof. Gustav Tschermak, *Vienna.*
1890. Geheimrath Prof. Heinrich Rosenbusch, *Heidelberg.*
1891. Prof. Charles Barrois, *Lille.*
1893. Prof. Waldemar Christofer Brögger, *Christiania.*
1893. Prof. Alfred Gabriel Nathorst, *Stockholm.*
1894. Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1895. Dr. Grove Karl Gilbert, *Washington, D.C.* (*U.S.A.*).
1896. Prof. Albert Heim, *Zürich.*
1897. Dr. Anton Fritsch, *Prague.*
1897. Dr. Hans Reusch, *Christiania.*
1898. Geheimrath Prof. Hermann Credner, *Leipzig.*
1898. Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*).
1899. Prof. Emanuel Kayser, *Marburg.*
1899. M. Ernest Van den Broeck, *Brussels.*
1900. M. Gustave F. Dollfus, *Paris.*
1900. Prof. Paul von Groth, *Munich.*
1900. Dr. Sven Leonhard Törnquist, *Lund.*
1901. M. Alexander Petrovich Karpinsky, *St. Petersburg.*
1901. Prof. Alfred Lacroix, *Paris.*
1903. Prof. Albrecht Penck, *Berlin.*
1903. Prof. Anton Koch, *Budapest.*
1904. Prof. Joseph Paxson Iddings, *Brinklow, Maryland* (*U.S.A.*).
1904. Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
1905. Prof. Louis Dollo, *Brussels.*
1905. Prof. August Rothpletz, *Munich.*
1906. Prof. Count Hermann zu Solms-Laubach. *Strasburg.*
1907. Hofrath Dr. Emil Ernst August Tietze, *Vienna.*
1907. Commendatore Prof. Arturo Issel, *Genoa.*
1908. Prof. Bundjirô Kôtô, *Tokyo.*
1908. Dr. Feodor Chernyshev, *St. Petersburg.*
1909. Prof. Johan H. L. Vogt, *Christiania.*
1909. Prof. René Zeiller, *Paris.*
1911. Prof. Armin Baltzer, *Berne.*
1911. Prof. Baron Gerard Jakob de Geer, *Stockholm.*
1911. M. Emmanuel de Margerie, *Paris.*
1912. Prof. Marcellin Boule, *Paris.*
1912. Prof. Johannes Walther, *Halle an der Saale.*

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1912.

Date of Election.

1874. Prof. Igino Cocchi, *Florence.*
1879. Dr. H. Émile Sauvage, *Boulogne-sur-Mer.*
1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1890. Geheimer Bergrath Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Weimar.*
1893. Prof. Aléxis P. Pavlow, *Moscow.*
1893. M. Ed. Rigaux, *Boulogne-sur-Mer.*
1894. Dr. Francisco P. Moreno, *La Plata.*
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Berlin.*
1899. Prof. Franz Lœwinson-Lessing, *St. Petersburg.*
1899. M. Michel F. Mourlon, *Brussels.*
1900. Prof. Ernst von Koken, *Tübingen.* (*Deceased.*)
1900. Prof. Federico Sacco, *Turin.*
1901. Prof. Friedrich Johann Becke, *Vienna.*
1902. Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1902. Prof. Samuel Wendell Williston, *Chicago, Ill.* (*U.S.A.*).
1904. Dr. William Bullock Clark, *Baltimore* (*U.S.A.*).
1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg.*
1904. Prof. Giuseppe de Lorenzo, *Naples.*
1904. The Hon. Frank Springer, *East Las Vegas, New Mexico* (*U.S.A.*).
1904. Dr. Henry S. Washington, *Locust, N.J.* (*U.S.A.*).
1906. Prof. John M. Clarke, *Albany, N.Y.* (*U.S.A.*).
1906. Prof. William Morris Davis, *Cambridge, Mass.* (*U.S.A.*).
1906. Dr. Jakob Johannes Sederholm, *Helsingfors.*
1908. Prof. Hans Schardt, *Zürich.*
1909. Dr. Daniel de Cortázar, *Madrid.*
1909. Prof. Maurice Lugeon, *Lausanne.*
1910. Prof. François Alphonse Forel, *Lausanne.* (*Deceased.*)
1911. Prof. Arvid Gustaf Högbom, *Upsala.*
1911. Prof. Charles Depéret, *Lyons.*
1912. Dr. Frank Wigglesworth Clarke, *Washington, D.C.* (*U.S.A.*).
1912. Dr. Whitman Cross, *Washington, D.C.* (*U.S.A.*).
1912. Baron Ferencz Nopcsa, *Temesmegye* (*Hungary*).
1912. Prof. Karl Diener, *Vienna.*
1912. Prof. Fusakichi Omori, *Tokyo.*
1912. Prof. Ernst Weinschenk, *Munich.*

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

'To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1831. Mr. William Smith.
1835. Dr. Gideon A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. Hugh Falconer.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Prof. A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron Leopold von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy.
1844. The Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. The Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. The Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir Henry De la Beche.
1856. Sir William Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Prof. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Prof. Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Prof. Gustav Bischof.
1864. Sir Roderick Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Prof. Carl F. Naumann.
1869. Dr. Henry C. Sorby.
1870. Prof. G. P. Deshayes.
1871. Sir Andrew Ramsay.
1872. Prof. James D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Prof. Oswald Heer.
1875. Prof. L. G. de Koninck.
1876. Prof. Thomas H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Prof. Bernhard Studer.
1880. Prof. Auguste Daubrée.
1881. Prof. P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. William Thomas Blanford.
1884. Prof. Albert Jean Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Descloizeaux.
1887. Mr. John Whitaker Hulke.
1888. Mr. Henry B. Medlicott.
1889. Prof. Thomas George Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John Wesley Judd.
1892. Baron F. von Richthofen.
1893. Prof. Nevil Story Maskelyne.
1894. Prof. Karl Alfred von Zittel.
1895. Sir Archibald Geikie.
1896. Prof. Eduard Suess.
1897. Mr. Wilfrid H. Hudleston.
1898. Prof. Ferdinand Zirkel.
1899. Prof. Charles Lapworth.
1900. Dr. Grove Karl Gilbert.
1901. Prof. Charles Barrois.
1902. Dr. Friedrich Schmidt.
1903. Prof. Heinrich Rosenbusch.
1904. Prof. Albert Heim.
1905. Dr. J. J. Harris Teall.
1906. Dr. Henry Woodward.
1907. Prof. William J. Sollas.
1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.
1910. Prof. W. B. Scott.
1911. Prof. Waldemar Christofer Brögger.
1912. Dr. Lazarus Fletcher.
1913. The Rev. Osmond Fisher.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. Gideon A. Mantell.
1836. Prof. G. P. Deshayes.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Prof. Edward Forbes.
1842. Prof. John Morris.
1843. Prof. John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape of Good Hope Fossils. M. Alcide d'Orbigny.
1849. Mr. William Lonsdale.
1850. Prof. John Morris.
1851. M. Joachim Barrande.
1852. Prof. John Morris.
1853. Prof. L. G. de Koninck.
1854. Dr. Samuel P. Woodward.
1855. { Dr. G. Sandberger. Dr. F. Sandberger.
1856. Prof. G. P. Deshayes.
1857. Dr. Samuel P. Woodward.
1858. Prof. James Hall.
1859. Mr. Charles Peach.
1860. { Prof. T. Rupert Jones. Mr. W. K. Parker.
1891. Prof. Auguste Daubrée.
1862. Prof. Oswald Heer.
1863. Prof. Ferdinand Senft.
1864. Prof. G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Dr. William Carruthers.
1870. M. Marie Rouault.
1871. Mr. Robert Etheridge.
1872. Dr. James Croll.
1873. Prof. John Wesley Judd.
1874. Dr. Henri Nyst.
1875. Prof. Louis C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. Robert Etheridge, jun.
1878. Prof. William J. Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. Ramsay H. Traquair.
1882. Dr. George Jennings Hinde.
1883. Prof. John Milne.
1884. Mr. Edwin Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Dr. Benjamin Neeve Peach.
1888. Dr. John Horne.
1889. Dr. A. Smith Woodward.
1890. Mr. William A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville Adelbert Derby.
1893. Mr. John George Goodchild.
1894. Dr. Aubrey Strahan.
1895. Prof. William W. Watts.
1896. Mr. Alfred Harker.
1897. Dr. Francis Arthur Bather.
1898. Prof. Edmund J. Garwood.
1899. Prof. John B. Harrison.
1900. Dr. George Thurland Prior.
1901. Dr. Arthur Walton Rowe.
1902. Mr. Leonard James Spencer.
1903. Mr. L. L. Belinfante.
1904. Miss Ethel M. R. Wood.
1905. Dr. Henry Howe Bemrose.
1906. Dr. Finlay Lorimer Kitchin.
1907. Dr. Arthur Vaughan.
1908. Mr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.
1910. Mr. Edward B. Bailey.
1911. Prof. Owen Thomas Jones.
1912. Mr. Charles Irving Gardiner.
1913. Mr. William Wickham King.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, BART., F.R.S., F.G.S.

'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1873. Mr. William Davies.
1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
1876. Mr. Alfred R. C. Selwyn.
1877. The Rev. W. B. Clarke.
1878. Prof. Hanns Bruno Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. The Rev. Peter B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. Waldemar C. Brögger.
1892. Prof. A. H. Green.
1893. The Rev. Osmond Fisher.
1894. Mr. William T. Aveline.
1895. Prof. Gustaf Lindström.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. Thomas F. Jamieson.
1899. { Dr. Benjamin Neeve Peach.
Dr. John Horne. }
1900. Baron A. E. Nordenskiöld.
1901. Mr. A. J. Jukes-Browne.
1902. Mr. Frederic W. Harmer.
1903. Dr. Charles Callaway.
1904. Prof. George A. Lebour.
1905. Mr. Edward John Dunn.
1906. Mr. Charles T. Clough.
1907. Mr. Alfred Harker.
1908. Prof. Albert Charles Seward.
1909. Prof. Grenville A. J. Cole.
1910. Prof. Arthur Philemon Coleman.
1911. Mr. Richard Hill Tiddeman.
1912. Prof. Louis Dollo.
1913. Mr. George Barrow.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

1873. Prof. Oswald Heer.
1874. Mr. Alfred Bell.
Prof. Ralph Tate.
1875. Prof. H. Govier Seeley.
1876. Dr. James Croll.
1877. The Rev. John F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. James Walker Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. Thomas Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Dr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward B. Wethered.
1891. The Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. Griffith John Williams.
1894. Mr. George Barrow.
1895. Prof. Albert Charles Seward.
1896. Mr. Philip Lake.
1897. Mr. S. S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.
1902. Sir Thomas H. Holland.
1903. Mrs. Elizabeth Gray.
1904. Dr. Arthur Hutchinson.
1905. Prof. Herbert L. Bowman.
1906. Dr. Herbert Lapworth.
1907. Dr. Felix Oswald.
1908. Miss Ethel Gertrude Skeat.
1909. Dr. James Vincent Elsden.
1910. Mr. John Walker Stather.
1911. Mr. Edgar Sterling Cobbold.
1912. Dr. Arthur Morley Davies.
1913. Mr. Ernest Edward Leslie Dixon.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, BART., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1876. Prof. John Morris.
1877. Sir James Hector.
1878. Mr. George Busk.
1879. Prof. Edmond Hébert.
1880. Sir John Evans.
1881. Sir J. William Dawson.
1882. Dr. J. Lycett.
1883. Dr. W. B. Carpenter.
1884. Dr. Joseph Leidy.
1885. Prof. H. Govier Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. Henry A. Nicholson.
1889. Prof. W. Boyd Dawkins.
1890. Prof. Thomas Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. Edwin Tulley Newton.
1894. Prof. John Milne.
1895. The Rev. John F. Blake.
1896. Dr. Arthur S. Woodward.
1897. Dr. George Jennings Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Dr. John Edward Marr.
1901. Dr. Ramsay H. Traquair.
1902. { Prof. Anton Fritsch. / Mr. Richard Lydekker. }
1903. Mr. Frederick W. Rudler.
1904. Prof. Alfred G. Nathorst.
1905. Dr. Hans Reusch.
1906. Prof. Frank Dawson Adams.
1907. Dr. Joseph F. Whiteaves.
1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.
1910. Dr. Arthur Vaughan.
1911. { Dr. Francis Arthur Bather. / Dr. Arthur Walton Rowe. }
1912. Mr. Philip Lake.
1913. Mr. S. S. Buckman.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. Wilhelm Waagen.
1879. Prof. Henry A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Prof. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. The Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Ed. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. Alfred J. Jukes-Browne.
1886. Mr. David Mackintosh.
1887. The Rev. Osmond Fisher.
1888. Dr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. Prof. Louis Dollo.
1890. Mr. Charles D. Sherborn.
1891. Dr. C. I. Forsyth Major.
1891. Mr. George W. Lamplugh.
1892. Prof. John Walter Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Prof. Percy Fry Kendall.
1895. Mr. Benjamin Harrison.
1896. Dr. William F. Hume.
1896. Dr. Charles W. Andrews.
1897. Mr. W. J. Lewis Abbott.
1897. Mr. Joseph Lomas.
1898. Mr. William H. Shrubsole.
1898. Mr. Henry Woods.
1899. Mr. Frederick Chapman.
1899. Mr. John Ward.
1900. Miss Gertrude L. Elles.
1901. Dr. John William Evans.
1901. Mr. Alexander McHenry.
1902. Dr. Wheelton Hind.
1903. Mr. Sydney S. Buckman.
1903. Mr. George Edward Dibley.
1904. Dr. Charles Alfred Matley.
1904. Prof. Sidney Hugh Reynolds.
1905. Dr. E. A. Newell Arber.
1905. Dr. Walcot Gibson.
1906. Mr. William G. Fearnsides.
1906. Mr. Richard H. Solly.
1907. Mr. T. Crosbee Cantrill.
1907. Mr. Thomas Sheppard.
1908. Dr. Thomas Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Mr. F. R. Cowper Reed.
1910. Dr. Robert Broom.
1911. Dr. Charles Gilbert Cullis.
1912. Dr. Arthur Richard Dwerryhouse.
1912. Mr. Robert Heron Rastall.
1913. Mr. Llewellyn Treacher.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1877. Prof. Othniel Charles Marsh.
1879. Prof. Edward Drinker Cope.
1881. Prof. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Dr. J. J. Harris Teall.
1891. Dr. George Mercer Dawson.
1893. Prof. William J. Sollas.
1895. Dr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. Edgeworth David.
1901. Mr. George W. Lamplugh.
1903. Dr. Henry M. Ami.
1905. Prof. John Walter Gregory.
1907. Dr. Arthur W. Rogers.
1909. Dr. John Smith Flett.
1911. Prof. Othenio Abel.
1913. Sir Thomas H. Holland.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1903. John Lubbock, Baron Avebury.
1906. Mr. William Whitaker.
1909. Lady Evans.
1912. Library extension.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1879. Purchase of microscope.
1881. Purchase of microscope-lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Purchase of scientific instruments for Capt. F. E. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Dr. Theodore T. Groom.
1902. Mr. William M. Hutchings.
1904. Mr. Hugh John Ll. Beadnell.
1906. Mr. Henry C. Beasley.
1908. Contribution to the Fund for the Preservation of the 'Grey Wether' sarsen-stones on Marlborough Downs.
1911. Mr. John Frederick Norman Green.
1913. { Mr. Bernard Smith. Mr. John Brooke Scrivenor.

AWARDS OF THE PROCEEDS OF THE 'DANIEL PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1903. Prof. Ernest Willington Skeats.
1904. Mr. Linsdall Richardson.
1905. Mr. Thomas Vipond Barker.
1906. Miss Helen Drew.
1907. Miss Ida L. Slater.
1908. Mr. James A. Douglas.
1909. Dr. Alexander Moncrieff Finlayson.
1910. Mr. Robert Boyle.
1911. Mr. Tressilian Charles Nicholas.
1912. Mr. Otway H. Little.
1913. Mr. Roderick U. Sayce.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				175	0	0
Arrears of Admission-Fees	88	4	0			
Admission-Fees, 1913	252	0	0			
				340	4	0
Arrears of Annual Contributions	126	0	0			
Annual Contributions, 1913, from Fellows	1900	0	0			
Annual Contributions in advance	70	0	0			
				2096	0	0
Sale of the Quarterly Journal, including Longmans' Account	......			150	0	0
Sale of other Publications	......			10	0	0
Miscellaneous Receipts	......			10	0	0
Interest on Deposit-Account	......			15	0	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	51	16	0			
Dividends on £267 6*s.* 7*d.* Natal 3 per cent. Stock	8	0	0			
				351	16	0
				£3148	0	0

[NOTE.—The accumulated interest on the Sorby and Hudleston Bequests, which will amount on December 31st, 1913, to £271 16*s.* 8*d.*, is not included in the above estimate of Income expected.]

the Year 1913.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House-Expenditure:						
Taxes		15	0			
Fire-Insurance and other Insurance	16	0	0			
Electric Lighting and Maintenance	50	0	0			
Gas	20	0	0			
Fuel	35	0	0			
Furniture and Repairs	50	0	0			
House-Repairs and Maintenance	50	0	0			
Annual Cleaning	20	0	0			
Washing and Sundry Expenses	30	0	0			
Tea at Meetings	20	0	0			
				291	15	0
Salaries and Wages, etc.:						
Assistant-Secretary	400	0	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	150	0	0			
Assistant-Clerk	105	0	0			
Junior Assistant	60	0	0			
House-Porter and Wife	94	0	0			
Housemaid	49	18	0			
Charwoman and Occasional Assistance	14	0	0			
Accountants' Fee	10	10	0			
				894	3	0
Office-Expenditure:						
Stationery	40	0	0			
Miscellaneous Printing	60	0	0			
Postages and Sundry Expenses	75	0	0			
				175	0	0
Library (Books & Binding)				250	0	0
Library Catalogue:						
Cards	20	0	0			
Compilation	50	0	0			
				70	0	0
Publications:						
Quarterly Journal, including Commission on Sale	1000	0	0			
Postage on Journal, Addressing, etc.	100	0	0			
Record of Geological Literature	120	0	0			
Abstracts of Proceedings, including Postage	105	0	0			
List of Fellows	40	0	0			
				1365	0	0
				3045	18	0
Estimated excess of Income over Expenditure				102	2	0
				£3148	0	0

BEDFORD McNEILL, *Treasurer.*

January 25th, 1913.

[NOTE.—The cost of Redecoration of the Society's Apartments, involving a probable expenditure of about £450, is not included in the above estimate.]

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1912	464	2	8			
,, Balance in the hands of the Clerk at January 1st, 1912	11	9	2			
				475	11	10
,, Compositions				210	0	0
,, Admission-Fees:						
Arrears	81	18	0			
Current	270	18	0			
				352	16	0
,, Arrears of Annual Contributions	200	13	0			
,, Annual Contributions for 1912:—						
Resident Fellows	1881	12	0			
Non-Resident Fellows	3	3	0			
,, Annual Contributions in advance	73	10	0			
				2158	18	0
,, Publications:						
Sale of Quarterly Journal: *						
,, Vols. i to lxvii (less Commission £11 1*s.* 5*d.*)	112	13	3			
,, Vol. lxviii (less Commission £3 1*s.* 11*d.*)	49	4	6			
				161	17	9
,, Other Publications (less Commission)				10	4	7
,, Extension of Library:						
Transfer from Prestwich Fund				91	5	3
,, Sale of Museum Drawers				56	4	3
,, Miscellaneous Receipts				10	5	0
,, Repayment of Income-Tax (1 year)				20	10	2
,, Interest on Deposit				14	8	11
,, Dividends (less Income-Tax):—						
£2500 India 3 per cent. Stock	70	12	8			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	14	2	6			
£2250 London & North-Western Railway 4 per cent. Preference Stock	84	15	0			
£2800 London & South-Western Railway 4 per cent. Preference Stock	105	9	4			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	48	15	6			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	7	11	0			
				331	6	0
				£3893	7	9

* A further sum is due from Messrs. Longmans & Co. for Journal-Sales, etc. £68 7 1

Year ended December 31st, 1912.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House-Expenditure:						
Taxes		15	0			
Fire-Insurance and other Insurance	16	3	5			
Electric Lighting and Maintenance	53	19	6			
Gas	14	10	3			
Fuel	37	4	0			
Furniture and Repairs	57	15	0			
House-Repairs and Maintenance	52	14	1			
Annual Cleaning	12	17	0			
Washing and Sundry Expenses	30	19	0			
Tea at Meetings	17	6	7			
Conversazione	19	3	0			
				313	6	10
,, Salaries and Wages:						
Assistant-Secretary	387	10	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	150	0	0			
Assistant-Clerk	100	0	0			
Honorarium to the retiring Assistant-Clerk	68	15	0			
Junior Assistant	55	13	0			
House-Porter and Wife	91	13	6			
Housemaid	49	18	0			
Charwoman and Occasional Assistance	15	1	11			
Accountants' Fee	10	10	0			
				939	16	5
,, Office-Expenditure:						
Stationery	23	18	11			
Miscellaneous Printing	62	0	3			
Postages and Sundry Expenses	71	7	3			
				157	6	5
,, Library (Books and Binding, &c.)				238	12	9
,, Extension of Library				179	13	2
,, Library-Catalogue:						
Cards	11	2	6			
Compilation	50	0	0			
				61	2	6
,, Publications:						
Quarterly Journal, Vol. lxviii, Paper, Printing, and Illustrations	992	19	0			
Postage on Journal, Addressing, etc.	104	18	5			
Record of Geological Literature	113	8	9			
Abstracts, including Postage	101	12	6			
List of Fellows	49	8	9			
				1362	7	5
,, Balance in the hands of the Bankers at December 31st, 1912:						
Current Account	108	16	5			
Deposit Account	500	0	0			
,, Balance in the hands of the Clerk at December 31st, 1912	32	5	10			
				641	2	3
				£3893	7	9

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

HENRY A. ALLEN, HENRY DEWEY, } *Auditors.*

BEDFORD McNEILL, *Treasurer.*

January 25th, 1913.

Statements of Trust-Funds: December 31st, 1912.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	32	3	8	By Cost of Medal	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	30	6	2	,, Award from the Balance of the Fund	21	13	8
,, Repayment of Income-Tax (1 year)	1	17	6	,, Balance at the Bankers' at December 31st, 1912	32	3	8
	£64	7	4		£64	7	4

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	21	3	6	By Award to the Medallist	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	37	13	8	,, Award from the Balance of the Fund	29	10	4
,, Repayment of Income-Tax (1 year)	2	6	8	,, Balance at the Bankers' at December 31st, 1912	21	3	6
	£61	3	10		£61	3	10

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	53	15	9	By Award to the Medallist	25	0	0
,, Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	66	5	0	,, First Award from the Balance of the Fund	22	13	6
,, Repayment of Income-Tax (1 year)	4	2	0	,, Second Award from the Balance of the Fund	22	13	6
				,, Balance at the Bankers' at December 31st, 1912	53	15	9
	£124	2	9		£124	2	9

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	44	8	1	By Balance at the Bankers' at December 31st, 1912	58	8	11
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	13	4	6				
,, Repayment of Income-Tax (1 year)		16	4				
	£58	8	11		£58	8	11

'Bigsby Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	3	6	8	By Balance at the Bankers' at December 31st, 1912	9	12	8
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	5	18	8				
,, Repayment of Income-Tax (1 year)		7	4				
	£9	12	8		£9	12	8

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	37	8	6	By Grant	2	2	0
,, Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	3	18	8	,, Balance at the Bankers' at December 31st, 1912	39	10	2
,, Repayment of Income-Tax (1 year)		5	0				
	£41	12	2		£41	12	2

'Prestwich Trust Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	86	6	5	By Grant towards cost of Extension of Library	91	5	3
,, Dividends (less Income-Tax) on the Fund invested in £700 India 3 per cent. Stock	19	15	4	,, Balance at the Bankers' at December 31st, 1912	16	0	10
,, Repayment of Income-Tax (1 year)	1	4	4				
	£107	6	1		£107	6	1

'Daniel Pidgeon Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	16	3	7	By Award	30	11	6
" Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	28	15	10	" Balance at the Bankers' at December 31st, 1912	16	3	7
" Repayment of Income-Tax (1 year)	1	15	8				
	£46	15	1		£46	15	1

SPECIAL FUNDS.

Hudleston Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	67	19	2	By Balance at the Bankers' at December 31st, 1912	102	19	2
" Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	32	19	2				
" Repayment of Income-Tax	2	0	10				
	£102	19	2		£102	19	2

Sorby Bequest.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1912	67	19	2	By Balance at the Bankers' at December 31st, 1912	102	19	2
" Dividends (less Income-Tax) on the Fund invested in £1000 Canada $3\frac{1}{2}$ per cent. Stock	32	19	2				
" Repayment of Income-Tax	2	0	10				
	£102	19	2		£102	19	2

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

BEDFORD McNEILL, *Treasurer.*
January 25th, 1913.

HENRY A. ALLEN, } *Auditors.*
HENRY DEWEY, }

Statement relating to the Society's Property: December 31st, 1912.

	£	s.	d.	£	s.	d.
Balance in the Bankers' hands, December 31st, 1912:						
On Current Account	108	16	5			
,, Deposit do.	500	0	0			
Balance in the Clerk's hands, December 31st, 1912	32	5	10			
				641	2	3
Due from Messrs. Longmans & Co., on account of the Quarterly Journal, Vol. LXVIII, etc.				68	7	1
Arrears of Admission-Fees	113	8	0			
Arrears of Annual Contributions	254	2	0			
				367	10	0
				£1076	19	4
Funded Property, at cost price:—						
£2500 India 3 per cent. Stock	2623	19	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502	15	3			
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898	10	6			
£2800 London & South-Western Railway 4 per cent. Preference Stock	3607	7	6			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	1850	19	6			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	250	0	0			
£2000 Canada 3½ per cent. Stock	1982	11	0			
				13,716	2	9

[NOTE.—*The above amount does not include the value of the Library, Furniture, and Stock of unsold Publications. The value of the Funded Property of the Society, at the prices ruling at the close of business on December 31st, 1912, amounted to £10,957 10s. 9d.*]

BEDFORD McNEILL, *Treasurer.*

January 25th, 1913.

Award of the Wollaston Medal.

In handing the Wollaston Medal, awarded to the Rev. Osmond Fisher, M.A., to Sir Archibald Geikie, K.C.B., Pres. R.S., for transmission to the recipient, the President addressed him as follows:—

Sir Archibald Geikie,—

More than forty years ago, in my earliest struggles with the elements of geology, I received much kindly encouragement from my revered teacher and relative, Osmond Fisher. Twenty years later it was my pleasure to follow his footsteps, and to profit by the closest scrutiny of his work, in the Isle of Purbeck. It is now my privilege to request you to forward to him, in accordance with a unanimous vote, the highest award which it is in the power of the Council of the Geological Society of London to bestow—the Wollaston Medal.

I have referred especially to his work on the Purbeck Beds, because it is that with which I have the closest acquaintance. Written as long ago as 1856, his paper on that remarkable group of strata has formed the basis of all subsequent investigations; but no less masterly was his account of the Bracklesham Beds of the Isle of Wight Basin, which followed in 1862. The two together placed him at once in the ranks of those pioneer-geologists who, self-trained in all branches of their science, laid the foundations of British Stratigraphy.

It is probable, however, that the name of Osmond Fisher will dwell in the memory of posterity more especially as that of the author of the 'Physics of the Earth's Crust.' First produced in 1881, that work was founded on geological reasoning and mathematical proof which it was within the power of few to appreciate. Its value, growing in recognition during the lapse of more than thirty years, is now acknowledged; and the book has taken rank as a classic, on what is perhaps the most recondite subject which a geologist can be called on to investigate.

It is needless to refer in detail to the papers on a variety of other subjects with which Mr. Fisher has enriched geological literature, for they have already been mentioned from this chair on the occasion of the presentation to him of the Murchison Medal. But to what was then said I will now add that we are rejoiced to

see him still maintaining his interest in current geological work at the great age of 95, and that it is a satisfaction to us to add this further proof of our appreciation of his labours.

Will you, therefore, be so good as to transmit this Wollaston Medal to Osmond Fisher as a recognition by the Council of the lasting value of his 'researches concerning the mineral structure of the Earth'?

Sir ARCHIBALD GEIKIE, in reply, said:—

Mr. PRESIDENT,—

No duty at once more honourable and agreeable could be entrusted to a Fellow of this Society, than to act as a deputy for one of the most venerable and esteemed of our colleagues, and to receive on his behalf the Wollaston Medal, which has been awarded to him in recognition of the value and distinction of his contributions to Geological Science. I have been favoured with a short statement from Mr. Fisher, which I will read.

'It is indeed a most gratifying surprise to me that the Council of the Geological Society should have considered me worthy of their highest honour, the Wollaston Medal. At my great age (95) I shall not be able to attend and to offer my grateful thanks in person. I think that the Council must have formed a higher opinion of my merits than I have, but I must not quarrel with that. I once had as a pupil a scion of the Wollaston family. He was an entomologist, and wrote a learned work upon the insects of Madeira. He described the insect-remains which I found in Lexden brick-pit.

'I am thankful to say that I am still able to take an interest in our science. I am engaged at present in a mathematical investigation of the effect of an elevated plateau, like the Himalayan, when below the horizon of a station, in increasing gravity there. It will have to be taken account of in drawing conclusions from observations on gravity in the plains of India. My friend Davison is helping me with the arithmetic, in which I cannot trust myself. Arithmetic was not taught at Eton when I was there. I am afraid that the chief interest in my problem will be mathematical. In all problems of attraction hitherto the curvature of the earth's surface has been neglected. I have taken account of it, I believe, for the first time.'

In receiving this Medal for transmission to our revered Associate, I should like to add an expression of my own indebtedness to the illuminating suggestiveness and clear presentation of his contributions to Physical Geology. It is astonishing and delightful to see him, at his advanced age, still full of mental alertness and enthusiasm, busy as ever in the continuation of the long series of mathematical investigations with which he has enriched geological

literature. He has set to all of us a noble example of modest, earnest, and unwearied devotion to the cause of our favourite science. Let us trust that the brave veteran may not only live to complete the research on which he tells us that he is engaged, but prolong for years to come his sunny and beneficent old age.

Award of the Murchison Medal.

The President then presented the Murchison Medal to Mr. George Barrow, F.G.S., addressing him in the following words:—

Mr. Barrow,—

It is a great pleasure to me to hand to one who has been my colleague for many years, a tribute paid by the Council of the Geological Society to a life spent in the furtherance of Geological Science.

In awarding to you the Murchison Medal they have borne in mind that you commenced your official career by investigations of a part of Yorkshire remarkable both for the development of Lower Mesozoic rocks and for its physical features, and by writing a terse and lucid account of it in the North Cleveland memoir. They remember, too, that after assisting in the mapping of the West Yorkshire dales, you proceeded to the Scottish Highlands, and that by there introducing modern petrographical methods, you obtained results which have left a permanent mark in the literature on that fertile source of geological controversy. Your paper in 1893 on an intrusion of muscovite-biotite-gneiss has taken high rank, not only as a storehouse of careful observations on the characters of igneous and metamorphic rocks, but as elucidating the problems connected with hypogene geology. It was followed by announcements of your discovery of chloritoid in Kincardineshire and of the possible occurrence of Silurian strata in Forfarshire; while in 1904 you threw much light on the difficult question of the relationship of the Moine Gneisses of Perthshire to the metamorphic rocks of other parts of Scotland.

On your transference to Devon and Cornwall the experience which you had gained was utilized in unravelling the structure of that tormented region, and in studying the phenomena presented by the

metamorphic aureoles round the granitic intrusions. Here also your paper on the high-level platform of Bodmin Moor proved that more recent phenomena were not escaping your attention. At the present time, the work upon which you are engaged in Warwickshire is already throwing much light on some obscure stratigraphy.

Will you allow me, as an old colleague who has had every opportunity of judging, to add my own testimony that your work, wherever you have been placed, has been characterized by that thoroughness and conscientiousness in the field which alone can lead to permanent advance in the interpretation of geological phenomena?

On behalf of the Council I beg you to accept this Medal and Award.

Mr. Barrow, in reply, said:—

Mr. President,—

I feel deeply the honour which the Society has conferred on me by the award of the Murchison Medal. I have spent many years working on those Highland rocks in which the founder of this Medal took so keen an interest. The Murchison Medal has now been awarded to several workers on these rocks, and as no two of us have come to the same conclusions, it is gratifying to feel that the Fellows of this Society can rely implicitly on the impartiality of its Council in its awards. I have to thank you very much for the kindly way in which you have spoken of my work; it is especially agreeable, as coming from an old colleague and the head of that branch of the service to which I belong, which makes it a special pleasure to receive the Medal from your hands.

Award of the Lyell Medal.

In presenting the Lyell Medal to Mr. S. S. Buckman, F.G.S., the President addressed him as follows:—

Mr. Buckman,—

The Lyell Medal is by custom associated more especially with palæontological research. It is, therefore, fittingly awarded to you, in recognition of the conspicuous place which you hold among British palæontologists, as regards both your intimate knowledge of species

and your philosophic treatment of your subject. While you are an eminent exponent of that school of thought and mode of study with which the name of Hyatt is associated, your own work exhibits a marked originality and independence of outlook. Moreover, not only is it pregnant with suggestive ideas, but it forms an example of pure scientific research having proved to be of value in practical application.

Your investigations on the genetic relationships of the Jurassic Ammonites are the best example of your specialized labours. In a great monograph on the Ammonites of the Inferior Oolite Series, and in other works, you have sought to apply with precision the principles which underlie the correlations between ontogenetic and phylogenetic growth. Your research among the Brachiopods is no less illuminating as an example of the application of evolutionary principles; and, in dealing with the fossil forms, you have illustrated the production of similar morphic sequences in separate stocks and the frequency of homœomorphy.

The zonal method has been applied by you to stratigraphical problems with exceptional minuteness and accuracy. So great is your experience in handling difficult questions of zonal correlation, that you have acquired powers of interpretation which seem almost instinctive.

From my own knowledge I can speak of the value of your services in revising collections in public museums, and in converting mere accumulations of fossils into orderly sequences, eminently instructive as regards both evolution of species and stratigraphical significance.

It is my privilege to hand to you this Medal and Award in recognition of brilliant and original palæontological research.

Mr. Buckman, in reply, said:—

Mr. President,—

It is with feelings of very great pleasure that I receive the unexpected honour of the Lyell Medal awarded to me by the Council; and when I listened to your kindly references to my work I felt that your recognition of its merits was far too flattering, especially when so much of what I hoped to accomplish still remains undone owing to certain causes. But it gives me particular pleasure to receive this award from your hands, for you belong to a body of

scientific men whose practical work in geological surveying enables them to judge the value of stratigraphical labours.

It is now 32 years since the Society did me the honour to accept a paper from my pen. My later work has followed that paper up, though in more detail in the nomenclature both of strata and of species. But my later work is guided by my interest in the study of evolution, good illustrative subjects being found among Ammonites and Brachiopoda. This stratigraphic and classificatory work was, and is the necessary, if somewhat monotonous spade-work for evolution; for it was useless to compile genealogies while the sequence of strata was unknown in detail, and while nomenclature included polyphyletic forms under the same designation.

Through attention to, and insistence on, the importance of apparently trivial details, the phenomenon of homœomorphy was discovered; and the reception accorded to homœomorphy has, at any rate, been cordial. But it involves a revision, almost a rewriting, of palæontology. Much of my earlier work I have revised; much of it I should like to rewrite.

Such spade-work finds perhaps its fullest expression in the publication 'Yorkshire Type-Ammonites'; for the bed-rock of nomenclature must be an exact knowledge of types. And I cannot let this opportunity pass without acknowledging the debt which I owe to my enthusiastic collaborator, Mr. J. W. Tutcher, who combines an excellent geological knowledge with unrivalled photographic skill. His work has been the making of that publication.

To you, Sir, and to the Council I tender my heartfelt thanks for an Award which encourages me to continue my researches.

Award of the Bigsby Medal.

The President then presented the Bigsby Medal to Sir Thomas Henry Holland, K.C.I.E., addressing him in the following words:—

Sir Thomas Holland,—

The Council have awarded to you the Bigsby Medal in recognition of the eminent services which you have rendered to Geology, more especially during your tenure of office in India. Appointed to the Geological Survey of India in 1890, you proceeded to enrich the 'Records' and other publications, not only with papers on petrological

and other scientific questions, but with the discussion of problems more directly bearing on the welfare and safety of the inhabitants of India. Under your Directorship, from 1903 to 1909, the Geological Survey of India maintained its high reputation ; while, at the same time, advantage was taken of your sagacity and extended geological experience to obtain your advice in the administration of Indian scientific affairs.

It is not possible for me to refer in detail to your published works. They range through petrology, mineralogy, stratigraphy, and seismology into the domain of geography, one of your later papers having been devoted to an account of the remarkable dissemination of salt which can be effected by wind. But I may emphasize, in the words of the founder of this Medal, the fact that you are not too young to have done much, and that you are not too old for further work. It is the hope of the Council that you will continue for many years at home the eminently useful career which you have commenced so auspiciously in India.

Sir Thomas Holland replied as follows :—

I deeply appreciate the honour which has been conferred on me by the Council, as well as the generous terms in which you, Sir, have referred to my work. Nothing could be more pleasing to a worker than to be enjoined by one's seniors to continue in work.

A glance over the list of my distinguished predecessors shows how abundantly each one subsequently fulfilled the intention of this Award, and thus one's feelings of satisfaction become tinged with those of great responsibility. At the same time, when one realizes that the Council hitherto has never made a mistake in its selection of a recipient for the Bigsby Medal, this feeling of responsibility becomes again blended with that of hopeful ambition.

In so far as this honour is a recognition of work already done, I should like to make it known to the Council that my chief aims in India have been to facilitate the work of my colleagues. No published work of my own has caused me more anxious care, or given me greater satisfaction, than the memoirs issued in the names of my colleagues on the Geological Survey of India ; it was because of their abundantly loyal support that a measure of success followed my administration, and it is because this honour in effect recognizes their good work, that it gives me peculiar pleasure.

Award from the Wollaston Donation Fund.

In presenting the Balance of the Proceeds of the Wollaston Donation Fund to Mr. William Wickham King, F.G.S., the President addressed him as follows :—

Mr. Wickham King,—

The Council have awarded to you the Wollaston Fund, to mark more especially their appreciation of your researches on the Permian Conglomerates of the Lower Severn Basin. Probably no group of British deposits called more urgently for investigation than the red rocks of the Midlands. Their remarkable conglomerates, breccias, and calcareous bands offered problems of the greatest interest; while the stratigraphical sequence and correlation throughout the country called for reconsideration. Though the story is not yet fully told, your paper marked a notable advance in its elucidation ; the Permian breccias of the Severn valley are inseparably connected in men's minds with your name.

The Council are aware that you are engaged upon other problems connected with the district in which you have laboured to such advantage, and make this Award, not only in recognition of what you have done, but in anticipation of equally good work to follow.

Award from the Murchison Geological Fund.

The President then presented the Balance of the Proceeds of the Murchison Geological Fund to Mr. Ernest Edward Leslie Dixon, B.Sc., addressing him in the following words :—

Mr. Dixon,—

The Murchison Fund has been awarded to you by the Council of our Society to mark their sense of the value of your detailed observations on the Carboniferous Limestone. Working in association with Dr. Vaughan, and armed with the knowledge which you had gained during your official survey of the region, you were able to combine detailed palæontological and stratigraphical observations in such a manner as to produce an exhaustive account of the varying geographical conditions under which the limestone of Gower came into existence. You have also provided us with an admirable

account, founded in part upon your own observations, of a remarkable overthrust exhibited in the Pyrenees. May I be permitted to add, from my own knowledge of a colleague with whom I have long been associated, my testimony to your zeal and to that carefulness in field-work which leaves no stone unturned and no note unmade? The Council in making this Award, anticipate with confidence further results from your labours.

Award from the Lyell Geological Fund.

In presenting the Balance of the Proceeds of the Lyell Geological Fund to Mr. Llewellyn Treacher, F.G.S., the President addressed him as follows:—

Mr. Treacher,—

The Council have awarded to you the Lyell Fund in recognition of the value of your contributions on the Chalk. In 1905, in association with Mr. Osborne White, you were able to add greatly to our knowledge of the fauna and zonal affinities of the Taplow phosphatic chalk. In the following year, with the same collaborator, you described some occurrences in Berkshire of phosphatic chalk not previously known, and also published the result of your joint investigations on the Upper Chalk of the western end of the London Basin, showing in detail the extent of the Tertiary transgression. While thus engaged you have not omitted to collect the relics which Neolithic and Palæolithic men have left in the Thames Valley. For my own part, I take this opportunity of acknowledging the great utility of such observations as yours in the work of the Geological Survey. We look forward to the continuance of your researches.

Awards from the Barlow-Jameson Fund.

The President then presented a moiety of the Proceeds of the Barlow-Jameson Fund to Bernard Smith, M.A., addressing him as follows:—

Mr. Smith,—

In awarding to you a part of the Barlow-Jameson Fund, the Council have borne in mind that our knowledge of the Glacial phenomena of Black Combe is largely due to your researches. In your admirable account of that region every branch of the enquiry

has received due consideration; but your description of channels now for the most part abandoned, though occupied during the Glacial Period by marginal streams or overflows, forms a special feature of your paper. In the course of your official work in Nottinghamshire you made good use of your opportunities to study the remarkable skerry-bands of the Keuper Marl, and found reason to connect their formation with the variations of the seasons. Lower Palæozoic rocks also have engaged your attention in Ireland.

This Award has been made in the expectation that you will continue the career so well begun, and will do yet more 'for the advancement of Geological Science.'

In handing the other moiety of the Proceeds of the Barlow-Jameson Fund, awarded to JOHN BROOKE SCRIVENOR, M.A., to Mr. CLEMENT REID, F.R.S., for transmission to the recipient, the PRESIDENT addressed him in the following words:—

Mr. REID,—

In the course of a rapid journey in Patagonia, Mr. Scrivenor found time to make observations on the sedimentary and igneous rocks and on the river-system of that country. From 1902, as a member of the staff of the Geological Survey, he was associated with you in Cornwall, and rendered valuable assistance in preparing the maps and memoirs illustrating the country around Newquay and the Land's End. In 1905 he was selected as Government Geologist in the Federated Malay States, and since his appointment has enriched our knowledge of that difficult region by papers on the mode of occurrence and mining of gold, tin, copper, and other ores, by descriptions of Archæan and igneous rocks, and by researches on the sedimentary sequence. Both in range of subject and in extent of travel he has distinguished himself as one of our leading exponents of the geology of the more distant parts of the Empire.

In transmitting to him a part of the Barlow-Jameson Fund, will you assure him that we at home watch with interest the work of our colleagues abroad, and will you express on our behalf the hope that he may long preserve the energy necessary for the prosecution of such arduous labours?

THE ANNIVERSARY ADDRESS OF THE PRESIDENT, AUBREY STRAHAN, Sc.D., F.R.S.

Since our last Annual Meeting we have lost by death no fewer than six distinguished foreign geologists, Prof. Brush and Prof. Zirkel from our list of Foreign Members, and Prof. Forel, Prof. von Koken, Prof. K. de Khrushchov, and Prof. Tarr from among our Foreign Correspondents. We have to mourn also the decease of twenty-eight Fellows of the Society, and among them many who had done much to advance geological science.

Though they were not Fellows of the Geological Society, I may be permitted to allude also to the deaths of five members of the British Antarctic Expedition—Scott, Wilson, Bowers, Oates, and Evans—on their return journey after attaining the South Pole. The details of the tragedy and the indomitable fortitude displayed by these men are known to you, but I will remind you of one incident. We learn that they had collected geological specimens, and that they carried them, after food and fuel had gone, until life gave out. Surely never before have inanimate objects been invested with so pathetic an interest.

In preparing the following obituary notices I am indebted for assistance to Dr. J. J. H. Teall, Mr. L. J. Spencer, Prof. E. J. Garwood, Dr. A. Smith Woodward, Mr. G. W. Lamplugh, Dr. J. Horne, Mr. H. W. Monckton, Mr. R. D. Oldham, and Mr. John Gerrard.

[For the data on which the following notice is founded I am indebted to an obituary published in the 'American Journal of Science' ser. 4, vol. xxxiii, p. 389.]

GEORGE JARVIS BRUSH was born on December 15th, 1831. While yet at school he developed, under the guidance of an enlightened master, a taste for mineralogy which he maintained for the rest of his life. After a brief period spent in business, he was compelled by an illness to seek a more open-air life. Having acquired an interest in farming, he studied agriculture and applied chemistry at Yale, and in 1850 became assistant-instructor in chemistry and toxicology at Louisville (Kentucky). In 1852–53, while assistant in chemistry at the University of Virginia, he published, in collaboration with Mr. J. Lawrence Smith, three papers on the 'Re-examination of American Minerals.' Feeling the necessity of

further study he then went to Germany, and, on receiving an appointment as Professor of Metallurgy in the Yale Scientific School in 1855, extended his experience by studying at the Royal School of Mines, London, and by visiting the chief mines and smelting-works of Great Britain and the Continent.

The scientific department of Yale College, which had lacked both funds and organization, was enriched in 1860 by the liberality of Mr. Joseph E. Sheffield, and became known as the Sheffield Scientific School. To its organization Prof. Brush thenceforward devoted his great administrative abilities; but, although as Secretary, Treasurer, and eventually President of the Board, he took a leading part in its affairs, he maintained to the last his interest in the subject in which he had specialized as a boy. His collection of minerals became notable for its completeness for the purposes of scientific study, and for the care with which it was arranged and catalogued. It was presented to the Sheffield Scientific School in 1904, and will remain at Yale as a permanent monument to its founder. Among his published works mention must be made of the 'Manual of Determinative Mineralogy.' He contributed also largely to Dana's 'System of Mineralogy,' and in his presidential address to the American Association for the Advancement of Science at Montreal in 1882, he summarized the early history of American Mineralogy.

He was elected a Foreign Correspondent of this Society in 1877, and a Foreign Member in 1894. Previously, in 1868, he had been elected a member of the National Academy of Sciences; and in 1886 he received the degree of Doctor of Laws at Harvard.

He died on February 6th, 1912, in the 81st year of an eminently active and useful life.

By the death of Geheimrath Professor Ferdinand Zirkel, the geological world has lost a pioneer in the science of microscopical petrography, and the Geological Society one of its oldest and most distinguished Foreign Members. He was born at Bonn on May 20th, 1838; and, although the greater part of his long and active life was spent away from that city, he always regarded it as his home, returning to it whenever his professorial and other duties permitted.

In 1855 Zirkel entered the University of Bonn, applying himself especially to chemistry and mineralogy, and to practical work in the mines of Rhineland, with a view to the career of a mining engineer. But, before he had completed his studies, the opportunity

of making a tour in Iceland and the Faröe Islands proved too tempting to be resisted. On returning from this tour he spent three months in Scotland and England, visiting some of our most important mining districts. He graduated at Bonn in 1861, making his observations in Iceland the subject of his inaugural dissertation.

We next find him working for a short time in Vienna, where his first important paper on microscopical petrography was published in 1862. By this time he had recognized the importance of Sorby's researches and the far-reaching possibilities of the new method of investigation.

In 1863 he became Professor at Lemberg. In 1868 he received a call to Kiel; and two years later (1870) to Leipzig, as successor to Karl Friedrich Naumann, the celebrated mineralogist. There he remained for nearly forty years, attracting students from all parts of the world by the excellence of his teaching and the charm of his personality.

This is not the occasion on which to refer in detail to his numerous original publications; two may, however, be mentioned, as being of especial interest to British and American geologists. In 1868 he made an extensive tour along the western coast of Scotland, visiting Arran, Mull, Iona, Staffa, and Skye, and collecting an extensive series of rocks for more minute study in the laboratory. The results of his observations, in which the microscope was applied to the study of the igneous rocks of that region, were published in 1871. Shortly after the appearance of this paper, Zirkel's services were secured by the United States Government for the examination and description of the rocks collected during the Geological Exploration of the Fortieth Parallel. This resulted in the publication, in 1876, of the large quarto volume on Microscopical Petrography, which forms vol. iv of the Geological Report by Clarence King.

The importance of the new method was now recognized all the world over, and communications based on it were appearing in the scientific periodicals of many lands. With this rapidly increasing mass of petrological literature Zirkel made himself thoroughly familiar, finally giving to the world the results of his unrivalled knowledge in the second edition of the 'Lehrbuch' (1893-94), the first edition of which had appeared in 1866. This is an encyclopædic work published in three large volumes.

Although Zirkel is best known as a petrologist, his services to pure mineralogy must not be overlooked. In 1862 he brought out

an important monograph on bournonite; and, after succeeding to the chair at Leipzig, he accepted the responsibility of keeping Naumann's well-known textbook up to date. This work has passed through fifteen editions, six of which have been edited by Zirkel.

Our late Foreign Member often visited this country, where he had many personal friends, including Sorby, to whom he dedicated his classic work on the 'Microscopic Structure & Composition of Basalts' (1870).

He was a man of sympathetic nature, a delightful companion, and a true friend. He took a deep personal interest in the welfare of his students, and they responded with almost filial affection. He received many honours from universities, scientific institutions, and from the State. His colleagues showed their regard for him by making him Rector of the University with which he was officially connected for so many years.

Zirkel was elected a Foreign Correspondent of the Geological Society in 1869, and a Foreign Member in 1880. In 1897 he was elected a Foreign Member of the Royal Society. He died at Bonn on June 11th, 1912, in the 75th year of his age. [J. J. H. T.]

By the death of François Alphonse Forel, who was elected a Foreign Correspondent in 1910, our Society has lost a naturalist of world-wide renown and one of the notable Swiss savants of the last half-century. He was born at Morges on February 2nd, 1841, on the shores of the lake to the investigation of which he was to devote so many years of his life.

He was educated at the Academy of Geneva, and attended the medical course at Montpellier. After a lengthened stay in Paris he proceeded to the University of Würzburg, where he took his Doctorate of Medicine in 1867, afterwards remaining there as prosector in the Department of Anatomy. In 1870 he returned to Switzerland, and was appointed Professor of Anatomy & Physiology in the University of Lausanne, a post which he held for 25 years. He retired from this chair in 1895, in order that he might pursue his favourite studies in various branches of natural philosophy. In the preface to his famous monograph on the Lake of Geneva he tells us how, at the age of thirteen, an interest in natural objects was first aroused in him by his father, in connexion with the investigation of the lake-dwellings of Morges, then in course of excavation.

During a period of nearly half a century, Forel had accumulated observations ranging over almost every branch of science. This catholic quality is well seen in the titles of his published papers, which exceed 300 in number and include, among other subjects, limnology, glaciology, seismology, meteorology, natural history, archæology, history, and biography. His chief work, 'Le Léman,' the three volumes of which appeared respectively in 1892, 1896, and 1904, treats of almost every branch of physical science and also biology, history, and political economy. It is impossible to touch here on more than one or two of the chief results arrived at by Forel in this remarkable work. In his chapter on the 'Origin of the Lake' he does not accept the view that the lake-basin owes its genesis to glacial excavation, but considers that the greater number of large Alpine lakes were in existence before the Pliocene Epoch, and were inhabited by faunas similar to those which we find at the present day. He favours, on the whole, the view first suggested by Charpentier, and afterwards developed by Heim, that a subsidence occurred during the Pleistocene Epoch which caused a reversed dip in the Alpine valleys, thus giving rise to sub-Alpine lakes. Among other notable results arising from his investigation of lakes was the discovery of a numerous and varied fauna living in the mud even at the greatest depths, not only in the Lake of Geneva, but in the other large Swiss and Italian lakes. To the investigation of problems connected with lakes he gave the name Limnology, and read a paper on this subject at the 6th International Geographical Congress in London, in 1896. In 1901 he published his admirable 'Handbuch der Seenkunde.'

One branch of limnology to which Forel contributed largely was the investigation of seiches. By means of a special tide-gauge he was able to show that in the water of the lake rhythmical movements take place, comparable to the movements of a pendulum. He showed that a connexion exists between seiches and the movements of the atmosphere, and he was still engaged in speculating on the causes of these phenomena within a few days of his death.

For the study of the varying colours of lake-water he invented a scale of colours or 'xanthometer': this consisted of eleven tubes containing varying mixtures of sulphate of iron and bichromate of potash, by means of which he obtained a series of tints varying from azure-blue, through green, to yellow.

After the year 1871, and especially between 1880 and 1890, his interest was aroused in questions relating to the structures and

motion of Swiss glaciers, and on this subject he contributed a series of papers to the 'Archives des Sciences Physiques & Naturelles de Genève.' As a result of these studies, he was led to investigate the granular structures of ice; to these attention had been first called by Hugi in 1843, but they had not been sufficiently considered in the controversies on the cause of glacier-motion during the middle and latter part of last century. In his paper on 'Le Grain du Glacier,' Forel laid stress on the marked increase in the size of grain which is observable between the névé and the terminal front of a glacier, and enunciated a 'grain-growth theory' which, however, he subsequently saw reason to abandon. During his researches he was led to speculate on the causes which controlled the periodic advance and retreat of the Swiss glaciers. It is thanks to him, indeed, that the variations of the Swiss glaciers have been studied since 1880, and that since 1895 an International Commission on Glaciers has been founded which has extended its observations to other lands, including Scandinavia, India, America, and even the Arctic and Antarctic regions. In all, Forel contributed upwards of fifty papers on this subject alone, and between 1883 and 1895 he edited the reports on Glacial Variation which appeared in the pages of the Journal of the Swiss Alpine Club.

As a result of his researches on seiches, Forel was led to take an interest in seismological phenomena, and, throwing himself with his usual enthusiasm into this new subject, he founded in 1878, in association with Hagenbach and Heim, the Swiss Commission for the study of earthquakes. In 1882 he constructed a scale for measuring the degree of intensity of earthquake-shocks, which was almost identical with one suggested at the same time by Prof. De Rossi of Rome. These two scales have since been combined by seismologists, and are known by the name of the 'Rossi-Forel scale.'

In meteorology Forel was among the first to point out the connexion between the accumulated temperatures of the year and the amount of sugar present in grapes; in archæology and history his name is well known, especially in connexion with investigations on the Lake-Dwellers or 'palafittures,' to quote the name by which he designated these prehistoric peoples, and he was one of the founders of the Société Vaudoise d'Histoire & d'Archéologie, to which he contributed several papers.

His researches also led him to the study of mirage, and his last communication to the Paris Academy of Sciences, on November 27th, 1911, when he was in his 72nd year, dealt with the fata

morgana which he had observed on the Lake of Geneva and the Mediterranean.

He was Life Member of the Société Helvétique des Sciences Naturelles, of which he had been an ordinary member since 1864; an Honorary Member of the Société Vaudoise, of which he had also been an ordinary member since 1864; an Honorary Professor of the University of Lausanne, on his retirement from the chair of Anatomy & Physiology; a Doctor *honoris causa* of the University of Geneva; an Honorary Member of the Société des Sciences Naturelles of Bâle; the first recipient of the William Huber Prize awarded by the Société Géographique de France: and a recipient of the Order of the Crown of Würtemberg. He was elected a Foreign Correspondent of this Society in 1910, and he was also an honorary member of both the Swiss Alpine Club and the British Alpine Club.[1] [E. J. G.]

Ernst von Koken was born at Brunswick on May 29th, 1860, and studied in the Universities of Göttingen, Zürich, and Berlin. He graduated at Berlin in 1884, and in the following year he became assistant to Prof. Beyrich in the Geological Institute of the University. At that time the rocks, minerals, and fossils were being removed from the old University buildings to the new Museum of Natural History, and Koken was associated with Dames in the laborious task of re-arranging the collection in the new cases and cabinets. In 1890 he was appointed Professor of Geology & Mineralogy in the University of Königsberg, and in 1895 he removed to Tübingen, where he held the corresponding Professorship until his death on November 21st, 1912.

Though interested in all branches of geological science, Koken devoted himself especially to palæontology and the use of fossils in stratigraphy. His Inaugural Dissertation in 1884 was the first serious attempt to identify the otoliths of bony fishes which are common in some Tertiary formations, and in 1888 and 1891 he made two more valuable contributions to the same subject. Among other early researches may also be mentioned his work on the reptilian remains from North German Wealden and Cretaceous formations, with important observations on the Mesozoic crocodiles. From 1899 onwards he devoted much attention to the Palæozoic gastropods, and published several papers noteworthy for the philo-

[1] We are indebted to the courtesy of Prof. Dr. Henri Blanc for much of the information embodied in this obituary notice.

sophical treatment of these fossils. After becoming Professor in Tübingen, he studied industriously the geology of Würtemberg, while still continuing his palæontological work; and a visit to the Salt Range in India in 1902 led him to take a special interest in Permo-Triassic problems. He contributed a remarkable, though somewhat speculative paper on the Permian ice-age to the centenary volume of the 'Neues Jahrbuch' in 1907. A complete list of his writings is published in the 'Neues Jahrbuch' for 1912, vol. ii, pt. 3.

While occupied with these numerous researches and his ordinary professorial duties, Koken was an editor of the 'Neues Jahrbuch' and the 'Geologische & Palæontologische Abhandlungen' from 1899, as also of the 'Palæontographica' from 1904, until his death. He planned and arranged the fine new Geological Institute of the University of Tübingen which was completed in 1902, and made extensive additions to the collection by his own field-work both at home and abroad. He was beloved by his students and all his associates, who deplore his untimely loss. He was elected a Foreign Correspondent of the Geological Society in 1900.

[A. S. W.]

Konstantin Dmitrievich Khrushchov (C. de Chrustschoff), who was elected a Foreign Correspondent of this Society in 1895, died on April 19th, 1912. His work on the artificial reproduction of minerals, by which he is best known, extended over a quarter of a century (1870–1895). It was commenced in Breslau, continued for a time in 1872 at the School of Mines in New York, and again in Breslau until 1890. He had studied also at Leipzig and Heidelberg, but he took his degree of doctor at Breslau. On his return to Russia in 1890 he was attached to the Chemical Laboratory, and afterwards to the Mineralogical Museum of the Imperial Academy of Sciences of St. Petersburg. From 1895 onwards he was Professor of Geology & Mineralogy in the Military Medical Academy at St. Petersburg.

His first paper 'On Silicic Acid & the Silicification of Woods,' in which he gave a preliminary account of his work on the artificial formation of crystallized silica, was published in 1872 in the 'American Chemist.' Then followed a pamphlet (Würzburg, 1878) giving the results, mainly petrographical, of a visit of several months' duration in 1873 to the Cerro del Mercado (or Iron Mountain), near Durango in Mexico. In succeeding years a series of mineralogical

and petrographical papers, some fifty in number, appeared under his name in French and German periodicals, principally in the Bulletin of the French Mineralogical Society (of which society he was a member), and in 'Tschermak's Mineralogische & Petrographische Mitteilungen.' Many of these papers were well illustrated by the author's own drawings, made under the microscope. In 1894 a lengthy monograph on spheroidal (orbicular) structures in holocrystalline rocks (granite, diorite, and gabbro) appeared in the Memoirs of the St. Petersburg Academy. His last paper, published in 1895, related to an improved form of the Babinet compensator for determining the strength of double refraction of mineral sections under the microscope.

The minerals which he prepared artificially include quartz, tridymite, and cristobalite (the three crystalline forms of silica), spinel, zircon, orthoclase, amphibole, diopside, biotite, analcite, and diamond. His method consisted in heating a dialysed solution of silica, together with various hydroxides, in a specially-constructed steel bomb at high temperatures (250° to 550° C.) for several months. Diamond was obtained in 1893 from a solution of carbon in molten silver.

Of other published work, mention may be made of his investigation and detailed descriptions of the inclusions in rock-forming minerals, and more especially the secondary glass-inclusions found in the minerals of certain rocks that had been caught up and acted upon by igneous magmas. The spectroscopic analysis of minerals and the chemical analysis of rare-earth minerals were also matters that engaged his attention. Petrographical work consisted in the description of material collected by him in America (including a leucite-rock from Lower California, Mexico), Volhynia, and Lake Ladoga. [L. J. S.]

By the sudden death of Ralph Stockman Tarr on March 21st, 1912, at the untimely age of 48, the Society lost an esteemed Foreign Correspondent, elected so recently as 1909, who had many personal friends in this country and was held by them in deep respect for his admirable qualities of character as well as for his high scientific attainments.

Born at Gloucester (Mass.), Tarr entered at Harvard University in 1881, and, after enforced interruptions for practical service in marine zoology and in geological field-work, he graduated in 1891. In 1892 he was appointed Assistant Professor of Dynamic Geology

and Physical Geography at Cornell University, and Professor of the same subjects there in 1896, occupying the chair of Physical Geography up to the time of his death. As an inspiring and sympathetic teacher, his influence upon his students was great, and has been acknowledged by them in many touching tributes to his memory. He was the author of some excellent textbooks of physical geography, geology, and economic geology, which have had wide circulation in this country as well as in America.

In 1896 Tarr had charge of the Cornell Expedition to Greenland, and wrote a series of illuminating papers on the glacial phenomena of the district visited.

In 1905–1906 he undertook researches in Alaska, in collaboration with his brother-in-law (Prof. L. Martin) and other assistants, for the United States Geological Survey, summarizing the results in 1909 in a monograph on the physiography and glacial geology of the Yakutat-Bay region, which is well known as a mine of information for all interested in glacial geology. Returning with Prof. Martin to the same district in 1909 and 1911, under the auspices of the National Geographic Society, to study the startling changes in progress in many of the Alaskan glaciers, he again proved his high capacity as observer and explorer, and his journey to Spitsbergen with the International Geological Congress party in 1910 gave him further experience of glacial phenomena. His vivid description of the spasmodic advances in many of the Alaskan glaciers, which he attributed to the after-effects of the big earthquake that shook the region in 1899, raised new problems in the physics of ice. These problems he set himself to solve, and had begun a series of experiments on the properties of ice, which were actively prosecuted up to his last days, and of which the first fruits were published shortly before his death. A fine monograph by Tarr & Martin on the physiographical results of the 1899 earthquake in the Yakutat-Bay region was published posthumously by the United States Geological Survey last year.

Cut down in the midst of his work and in the plenitude of his powers, Tarr had already done much and had planned to do more. The loss to science is heavy, and to his personal friends irreparable. He was married in 1892, and leaves a widow and two children.

[G. W. L.]

By the death of Ramsay Heatley Traquair the Society has lost one of its most distinguished Fellows and one of the prominent leaders in fossil ichthyology. Born at the Manse, Rhynd (Perth-

shire), in 1840, he received his early education in Edinburgh, where, as a boy, he showed his bent towards natural science. He became a collector of shells, butterflies and moths, and he strolled along the sea-shore to examine the rocks. He was wont to relate that his keen interest in fossil fishes was first aroused when hammering the ironstone-nodules in the Wardie Shales, which revealed to him a fragment of a Palæoniscid fish. Thereafter he passed through the medical curriculum at the University of Edinburgh, and graduated in medicine. His skill as a dissector attracted the notice of Prof. Goodsir and Sir William Turner, who was then Senior Demonstrator in Anatomy. This led to his appointment as one of the Demonstrators in that department. At Goodsir's suggestion he studied the asymmetry of the flat fishes, and chose this subject for his medical thesis, for which he was awarded a gold medal.

In 1866, he became Professor of Natural History in the Royal Agricultural College, Cirencester; in 1867, Professor of Zoology in the Royal College of Science, Dublin; and in 1873, he was appointed Keeper of the Natural History Collections in the Museum of Science & Art, Edinburgh—a post which he held until his retirement in 1906. The last of these appointments gave him exceptional facilities for pursuing the study of ichthyology, which he had chosen as his special line of research. He acquired for the Museum a magnificent series of fossil fishes, chiefly from the Old Red Sandstone and Carboniferous rocks of Scotland. The methods adopted by him while investigating these organic remains revolutionized this branch of enquiry. His work was essentially based on morphological structure, and not on the mere outline of the body nor on the configuration of scales and teeth.

Throughout his long and active career he published numerous papers, chiefly on fossil fishes, which have appeared in the Monographs of the Palæontographical Society, the Transactions of the Royal Society of Edinburgh, and the Proceedings of the Royal Society. His researches were of especial significance to the zoologist, by reason of the light thrown, in some conspicuous instances, on the question of evolution. Thus, early in his career, he showed that the Palæoniscidæ were more closely allied to the recent sturgeon than to the existing *Lepidosteus*, with which they had previously been compared. He further pointed out that the Platysomidæ were a specialized offshoot from the Palæoniscidæ. The new fish-fauna, discovered by the officers of the Geological

Survey in the Silurian rocks of the South of Scotland, led him to the conclusion that the Cœlolepidæ, though not actual sharks, had probably a common origin with the primitive Elasmobranchs. He also showed that the armour-plates of the genera *Psammosteus*, *Drepanaspis, Pteraspis,* and *Cephalaspis* had been formed by the fusion of the Cœlolepid scales one with the other and with hard tissue developed in a deeper layer of the skin.

To Scottish geologists his services were of the highest value, on account of their bearing on the stratigraphy of the Old Red Sandstone and Carboniferous formations. He had a thorough knowledge of the vertical range and distribution of the fossil fishes contained in these two systems in Scotland. By means of the fishes he arranged the Carboniferous rocks in two great divisions, drawing the boundary-line about the horizon of the Millstone Grit. Following the classification of Murchison and Salter, he regarded the Orcadian rocks as of Middle Old Red Sandstone age, and pointed out the existence of three fish faunas in that division in Caithness. Advancing further, he called attention to the occurrence of three fish faunas in the Upper Old Red Sandstone on the south side of the Moray Firth, the highest of which (Rosebrae) yielded an assemblage similar to that found at Dura Den.

The artistic restorations of fossil fishes with which he enriched his memoirs are worthy of special mention. They have been frequently reproduced in geological publications.

Traquair was elected a Fellow of the Geological Society of London in 1874, and of the Royal Society in 1881. In 1878 and 1901 respectively the Royal Society of Edinburgh awarded to him the Neill and the Macdougall-Brisbane Medals; in 1901 the Geological Society awarded to him its Lyell Medal, and in 1907 he received from the Royal Society one of its Royal Medals. In 1893 he received the honorary degree of LL.D. from the University of Edinburgh. He died on November 22nd, 1912. [J. H.]

R. Bruce Foote, who died on December 29th, 1912, joined the Geological Survey of India in September 1858, and retired in September 1891. His service was almost entirely spent in the Madras Presidency, where he examined and described, in conjunction with Dr. W. King, the Kadapah and Karnul Systems; our knowledge of the Upper Gondwana and the Cretaceous of the eastern coast is very largely due to his labours, as also the recognition and separation of the Dharwar System. Though

belonging to the older school of geology, and though all his work on the Archæan rocks was done before the introduction of modern methods of petrographical research, he recognized the importance of the results of their application; and it must be placed to his credit that, without their aid, he succeeded in establishing the division of the Archæan rocks into two entirely distinct systems, a division which has been found to hold good in all other regions where an extensive area of Archæan rocks is exposed and has been studied with care.

After leaving the Survey he entered the service of the Baroda State for a time, and afterwards that of the Mysore Government, where he organized a State geological service. Besides his purely geological work he was one of the earliest discoverers, and later a most enthusiastic investigator of relics of ancient man in Southern India; he formed an extensive collection of stone-implements, which is now deposited in the Madras Museum, and was for long recognized as a leading authority on this branch of research, which formed the subject dealt with in a paper published in vol. xxiv of the Quarterly Journal of this Society. He was elected a Fellow of the Geological Society in 1867. [R. D. O.]

By the death of Captain ARTHUR WILLIAM STIFFE on August 14th, 1912, we lose one of the regular attendants at our meetings. Stiffe was mainly educated at the Stuttgart Polytechnic, where he gained a silver medal for higher mathematics. In February 1849, being in his 18th year, he entered the navy of the East India Company as midshipman. He was lieutenant of the steam-frigate *Ajdaha* during the Persian war of 1856–57, and was present at the capture of both Bushire and Muhamra, receiving a medal for his services. He was then employed in making hydrographic surveys of the Persian Gulf and other areas for the Indian Government.

When on leave in England after the Persian war he studied engineering under James Abernethy, and was subsequently appointed Engineer-in-Chief of the cables laid in the Persian Gulf by the Government of India. On the abolition of the Indian Navy in 1857, he was appointed to the Royal Indian Marine, and served in it until he retired with the rank of Commander in April, 1888.

In December 1873, a paper by Stiffe on the 'Mud-Craters & Geological Structure of the Mekran (Baluchistan) Coast' was communicated by Ramsay to this Society, and in 1874 he became one of our Fellows. Other communications by him will be found in the Quarterly Journals for 1884 and 1890.

In 1879 Stiffe was appointed Port Officer at Calcutta, and in 1890 he was Engineer-in-Chief of the Halifax-Bermuda cable, which he successfully laid. He was the author of sailing directions for the Persian Gulf and other seas, and was a Younger Brother of the Trinity House.

Stiffe joined the Geologists' Association in 1894, and served on the Council of that Association from 1902 to 1908, during a part of which time he was Vice-President.

During his latter years he was accustomed to spend some weeks in the summer in Norway. Returning home at the end of July, apparently in good health, he celebrated his 81st birthday with his family at Goring. Two days afterwards, on Wednesday, August 14th, 1912, the end came suddenly.

Captain Stiffe married in 1863 Henrietta, daughter of John Stone, J.P., D.L. for Buckinghamshire, and they had two sons and a daughter. He was a man of great energy and of a most genial disposition, and will be much missed by his large circle of friends among geologists. [H. W. M.]

Joseph Dickinson was born on November 24th, 1818, at Newcastle-on-Tyne. He received his early education at Dr. Bruce's school in that town, but in 1833 became a pupil of Mr. Thomas Sopwith, F.R.S., a mining and civil engineer of eminence. During the spring terms of 1839–40 he conducted the preliminary classes of Sir Charles Lemon's Experimental Mining School at the Royal Institution, Truro. In 1840 he entered on active service at the Dowlais Ironworks and Mines, and in 1842 set out the first railway-sidings at the Bute Docks, Cardiff. Leaving Dowlais in 1847, he spent three years at the Nithsdale Ironworks, Scotland, where he laid out railways and opened mines. In 1850, the first Act of Parliament for the Inspection of Mines in Great Britain having been passed, Joseph Dickinson was one of the four inspectors then appointed, and was placed in charge of Lancashire, Cheshire, North Wales, Staffordshire, Shropshire, and Worcestershire. For 41 years Mr. Dickinson well served his country. He was engaged on numerous Government enquiries and missions, and in 1866 was appointed a member of the Royal Coal Commission, of which he was the sole survivor when the Royal Commission on Coal-Supplies reported in 1905. On December 31st, 1891, at the age of 73, he resigned his post as Inspector of Mines, but till the day of his death maintained an active interest in the practical applications of

geology. He was elected a member of the Manchester Geological & Mining Society in 1856, and was President in 1861, 1877, and 1887. Retaining his faculties unimpaired to the last, he attended constantly and spoke frequently at the meetings. Among the numerous papers contributed by him, his section of the Coal Measures of Lancashire, and his reports on the rock-salt and brine-deposits of Cheshire are of high value.

He was elected to the Geological Society of London in 1842, and at the time of his death was 'father' of our Society. He contributed a paper on the 'Jackstones' of Merthyr Tydvil in 1846, but during most of the 70 years of his Fellowship his interests were chiefly centred in Manchester scientific circles. He died on April 27th, 1912, at the age of 93. [J. G.]

[For the information on which the following notice is founded I am indebted to the 'Geological Magazine' for 1912, p. 525.]

Robert Ashington Bullen died on August 14th, 1912. Born in 1850 at St. George's, Bermuda, he came to England at the age of 6, and was educated at Gosport, eventually taking a B.A. degree in London University. In 1875 he was ordained, and after spending some years in teaching, became Vicar of Shoreham (Kent). Here he was thrown into close companionship with Prestwich, and was inspired to commence investigations on the superficial deposits of the Chalk Downs. Latterly he had devoted himself more especially to a study of the land and fresh-water mollusca which are associated with early human remains, and to the implements of flint and bone identified with Palæolithic and Neolithic man. His work on non-marine mollusca was of a high order, and his papers on the æolian deposits of the coast at Étel; on fossil mollusca from Alcudia (Mallorca) and on Manresa (Cataluña); and on the geology of his birth-place, the Bermudas, especially merit attention.

He was elected into the Geological Society in 1891, and was a member of several other Societies. Few but his most intimate friends can have realized how much kindness and liberality were concealed by his natural modesty and dread of ostentation.

James Parker, best known as an antiquary, was born in 1833, and died on October 10th, 1912. He was educated at Winchester, and received an honorary degree of M.A. at Oxford in 1877. His activities in archæological research are manifested chiefly in the Proceedings of the Oxford Architectural & Historical Society, but he was publisher also of the 'Early History of Oxford,' of the

'A.B.C. of Gothic Architecture,' and of the 'Introduction to Gothic Architecture.' In geology he did much useful work in the neighbourhood of Oxford, collecting fossils from the Oolitic rocks, and among them some saurian remains which are described in Phillips's 'Geology of Oxford.' He had assisted also in the exploration of caves in Somerset. He was elected a Fellow of the Geological Society in 1867.

John Morison, who died on April 1st, 1912, was a distinguished medical man. After passing through Guy's and University College Hospitals, he took the degree of M.D. at Edinburgh University in 1865, and in the same year became a member of the Royal College of Surgeons of England. While holding many medical posts, including that of Medical Officer of Health of St. Albans, he found time to contribute several papers to the Hertfordshire Natural History Society, and to occupy the presidential chair of that society in the years 1905–1907. His attention was drawn chiefly to the outcrops of Chalk and especially of the Chalk Rock in the neighbourhood, and in the course of years he had collected a large number of fossils, which he presented to the Hertfordshire County Museum. He was elected a Fellow of the Geological Society in 1887.

William Henry Pickering was born on October 1st, 1858, and was educated at St. Peter's School, York. In 1881 he obtained his certificate as a colliery-manager, and in 1883 was appointed an Inspector of Mines, serving as assistant-inspector in South Staffordshire, as chief inspector in the Yorkshire & Lincolnshire District, and eventually as divisional inspector for the Yorkshire & North Midland Division. In 1904, having been lent by the Imperial Government to the Government of India for three years as inspector of mines, he continued the work begun by Mr. James Grundy, the first inspector of mines in India, and introduced into practice the Indian Mines Act of 1901. Mr. Pickering was prominent in the establishment of the Mining & Geological Institute of India, acting as the first secretary. At the time of his death he was President of the Indian Mining & Geological Club, London, of which he was the founder. After his return he held office in various mining and engineering societies, and was the author of several papers on mining questions. In 1910 he was awarded an Edward Medal of the first class for gallantry in

attempting the rescue of a miner after an accident in a Yorkshire colliery. On July 9th, 1912, while heroically leading a party at Cadeby Colliery in the hope of effecting rescues after an explosion of firedamp, with full knowledge that the danger was imminent, he lost his life through the gas exploding a second time.

Sir CHARLES WHITEHEAD, J.P. and D.L.Kent, was born in 1834. He was elected to the Geological Society as long ago as 1872, but devoted himself chiefly to the study of agriculture in all its branches. On this subject he became a well-known authority, and served on the Royal Commission on Agriculture in 1893–97. He received the honour of knighthood in 1907. He died on November 29th, 1912.

JOHN SAMUEL PHENÉ died on March 11th, 1912, in his ninetieth year. He served as Master of the Clothworkers' Company in 1906–1907, and was a Vice-President of the Royal Society of Literature. He was elected into the Geological Society in 1886, and for several years served on the Council of the Palæontographical Society. He was perhaps best known as the designer of a house in Oakley Street, Chelsea, which he intended to represent the Château Savigny in Central France, where his Huguenot ancestors lived.

MUCH attention has been devoted of late years to the form and structure of the Palæozoic platform upon which the Secondary rocks of England rest. The interest in it has been centred chiefly upon the possible existence of profitable coal-fields, but we must remember that it is to the search for these that we are indebted for the means of pursuing other investigations which may not be financially important, but are of much scientific interest.

The configuration of the platform came up for consideration about six years ago, when some pendulum-experiments on variations in gravity were being made at Greenwich and Kew by Col. Burrard, preliminary to transporting the apparatus to India for the continuance of observations in that country. I then collected such data as were available, and prepared a map showing a contour-line drawn upon the surface of the platform at 1000 feet below sea-level. The map was published in 1908 (Survey of India, Professional Paper, No. 10), but since that date so much fresh evidence has so come to hand as to render possible considerable additions to the conclusions then drawn.

Upon the map thus revised (Pl. A, facing p. lxxviii) all noteworthy borings are shewn, so far as regards Central and Southern England. Upwards of forty of them, made in search either of coal or water, have been carried down to the Palæozoic platform, and against each is placed the depth in feet below sea-level at which the platform was met. Against the others, which failed to reach the platform, the depth attained is indicated, but is distinguished by a difference in type and by being placed in parentheses with the symbol +.

Though the borings are scattered with some abundance over parts of the area illustrated, the platform remains unknown in two regions. You will notice that it has not been reached anywhere south of a line drawn through Brabourne, Slough, and Burford, though some of the borings have attained a depth of nearly 2000 feet. Further, it may be pointed out that no attempt has been made to reach it in a broad tract extending from the estuary of the Thames north-westwards between Ware and Weeley.

Contour-lines drawn at intervals of 500 feet upon the surface of the platform have been inserted, wherever there is sufficient evidence of their position. Thus a contour-line at 1000 feet below sea-level (indicated on Pl. A as −1000) can be drawn with fair precision through Kent and to the south and east of London, though its position in the intervening area is not known. This same contour-line also separates Weeley, Harwich, and Lowestoft on the one hand, from Stutton and Culford on the other. A second contour-line drawn at 500 feet below sea-level can be located on the sides of a valley in the platform northwards from Rugby, and can be followed thence along a meandering course with a general south-easterly trend between Calvert and Wytham, where it turns north-eastwards past Ware. The evidence does not suffice for the insertion of any lines between Ware and Culford; but the fact that at Saffron Walden between these two places Oolitic rocks exist, although they are absent on either side, proves that the area has been one of depression in Oolitic times, and is not unlikely to be one of low elevation now. Lastly, a contour-line could be drawn with considerable precision at sea-level; but it suffices for my purpose to show the areas in which the Palæozoic rocks emerge from beneath the Secondary rocks into the open air. On these areas contour-lines at 500 and 1000 feet above sea-level could easily be added, though they would indicate, not the original features of the platform, but those which it has acquired through denudation since it was exposed to the air, which is not part of my present subject.

It will be seen from this map (Pl. A, facing p. lxxviii) that in two regions the platform is known to attain a depth of more than 1500 feet below sea-level, namely in the south and towards the north-east. Between the two it forms comparatively high ground, with a general trend to the south-east, as shown both by the -500 and the -1000 foot contour-lines. No connexion, however, between its features and its geological structure appears, so far as our limited knowledge of the latter enables us to judge. For example, Cambrian and Silurian strata enter into the composition of the highest parts of the platform at Calvert, and into the lowest part at Harwich and Lowestoft; while the Coal Measures in Kent form higher ground than do the highly inclined older Palæozoic rocks anywhere near them. Nor does the form of the platform give any obvious clue to the strike of the rocks that compose it.

This character is not in accordance with what is observable in a Palæozoic area which has been exposed to subaërial denudation. In such a case, however complete the original planation has been, the effect of erosion has been to develop features dependent upon the relative resistance offered by the rock-masses. As a rule, though not invariably, the Coal Measures survive only in basins.

In seeking an explanation of its form we remember in the first place that the greater part of the platform has never been exposed to subaërial waste since it was planed by marine agencies. It has suffered denudation in various parts at various epochs. Much of it was trenched in Triassic, or planed down in Jurassic times; some of it contributed débris to Lower Cretaceous formations, while not a little was levelled in Upper Cretaceous times before it was overspread by the Gault. But, in every case except the first-mentioned, it was immediately overspread by marine sediments, and has remained so covered ever since. There has, consequently, been no opportunity for the development of the characteristic sculpturing of subaërial denudation.

A still more important cause, however, is to be sought in the warping which the platform has undergone since its last planation. That the faults and folds which are observable in the Secondary rocks would be recognizable in the platform is not probable; they are, on the contrary, essentially surface-phenomena, and may be regarded as the efforts of a skin to adapt itself to changes in form of an underlying body. But that there has been tilting and warping of the platform is certain, and that it has been intermittent and oscillatory is capable of proof as for example in the case of the

Wealden Anticline, which has been shown by Mr. Lamplugh to have been superimposed upon a syncline. In fact, owing to the swelling out of the Lower Cretaceous and Upper Oolitic rocks under the arch, the anticlinal structure disappears downwards, and is replaced in the Kimmeridge Clay by a gentle synclinal structure: a relic, doubtless, of a more pronounced syncline which has been flattened by the post-Oligocene movement.[1] The coincidence may not be so strange as appears at first sight, for it is not infrequently found that liability to movement, whether upward or downward, is more or less confined to certain tracts. We can hardly suppose, however, that the later warping has generally been so arranged as to counteract precisely the effects of earlier movements.

In the limited time at my disposal it is impossible to discuss the effects of all the movements which have affected the platform since its planation, and I propose to confine my remarks to the latest and most energetic, those, namely, that came into operation between Oligocene and Pliocene times, and were demonstrably responsible for the geological structure of the South and East of England. For the purposes of this investigation I have selected a single plane in the Upper Cretaceous rocks, which has once been horizontal or approximately so, and have endeavoured to ascertain the magnitude of the distortions that it has undergone.

The base of the Gault appeared, after some consideration, to be the most suitable plane for the purpose. It is recognizable over a wider area and with more certainty than any other, while by choosing it I eliminated all the disturbances which had tilted the Lower Cretaceous and Jurassic previously to the deposition of the Upper Cretaceous rocks. It is true that the lowest beds of the Gault are not always present, and that the assumption that the plane was ever precisely horizontal and continuous would be unsound; but the departure from the horizontal is likely to have been trifling in comparison with the figures with which we are concerned, and insufficient materially to affect the conclusions.

In the base of the Gault, therefore, I have determined the altitude of as many points as possible, and from these data have constructed a map (Pl. B, facing p. lxxviii) showing contours at intervals of 500 feet, relative to the present sea-level.

The data on which the contours have been drawn have been derived from several sources. In the first place, the altitude of the base along visible outcrops was determined at frequent intervals.

[1] 'Mesozoic Rocks of Kent' Mem. Geol. Surv. 1911, p. 94.

This, combined with a number of well-sections near the outcrop, rendered possible the tracing of the line along which the base of the Gault lies at sea-level, that is the contour-line marked 0 on the map. Next, the deep borings in which the base of the Gault has been identified provided a series of points of precision. There were also available a large number of well-sections which, without reaching the base of the Gault, gave the level of the base of the Chalk or in other ways provided materials for an estimate. Lastly, when all other evidence failed, I used the numerous well-sections which have proved the level of the top of the Chalk under Tertiary beds, and estimated the thickness of the Upper Cretaceous rocks from a consideration of the nearest deep boreholes or measured sections. These last estimates are open to the objection that the Tertiary beds cut across the Chalk, in places markedly so. In the western and north-western parts of the area this method could only be used with caution. For the most part, however, the results obtained were so consistent that my confidence in them was somewhat restored.

Altogether seven contour-lines, ranging from 500 feet above the sea (shown on the map as +500) to 2500 feet below the sea (shown as −2500) have been traced. Of these the + 500 line is evidenced in a few places only, where a neighbouring outcrop either attains or closely approximates to that height, as at Leighton Buzzard, near Bletchley, in the Vale of Wardour, north-west of Penshurst, in the Weald, in the Isle of Wight, and in Dorset and Devon. The −1000 line has been drawn, so far as regards the London Basin and the ground north of it, mainly by reference to deep borings. All lines below −1000 are confined to the Hampshire Basin. They have been drawn by reference to the level of the top of the Chalk as found in borings, and by consideration of the thickness of the Upper Cretaceous rocks as developed in the nearest outcrops.

The map thus constructed gives a comprehensive view of the various flexures under consideration. It illustrates, in the first place the increase in intensity and frequency of the folding towards the south, and shows how in each syncline the axis hugs the southern margin. You may notice, for example, the broad spacing of the 0, −500, and −1000 lines on the northern side of the London Basin, and the comparative crowding of the same lines on the southern side. The two sides of the Hampshire Basin not only show the same difference, but the greater depth of the syncline as compared with that of the London Basin is well brought out.

It becomes apparent also, that neither the major anticlines nor synclines are simple in structure; they are made up of subsidiary folds which, though individually discontinuous, maintain effective continuity. Thus the London Basin includes two hollows, the one under the estuary of the Thames, the other west-south-west of London, close under the steep uplift of the Hog's Back. Subsidiary folds occur in the Wealden Anticline, both in the area from which the Chalk has been denuded and in that where the arch is more perfect. The overlapping and replacing anticlines in the Isles of Wight and Purbeck are readily recognized.

There are other points which I am tempted to mention, though briefly, for they scarcely form part of my present subject. It will be noticed that in the Chalk escarpment which extends across England from Lincolnshire to Dorset there are some rather abrupt changes in strike, all of which produce an anticlinal structure. Between Lincolnshire and Norfolk (beyond the northern margin of Pl. B) the strike changes from N. 30° W. to north and south; near Culford it changes to W. 35° S.; near Goring it changes from E. 30° N. on the north side of the Thames to east and west in the White Horse Hills on the south side of the river; farther south it is interrupted by the Pewsey and Wardour Anticlines.

In every case a breach has been effected in the escarpment, and a line of drainage traverses it in the direction of general dip. In the Wealden area a notable change of strike occurs near the centre of the northern scarp at Maidstone, and here the ridge is traversed by the Medway. I am not aware that any of the other breaches in the North and South Downs coincide with changes of strike, but the coincidence in the cases which I have mentioned is sufficiently frequent to be significant. The subject deserves further investigation.

Again, the map gives a comprehensive view of the general tilt which turned the drainage of England eastwards, and of the particular lines of syncline and anticline which determined the courses taken by the rivers. At the south coast our evidence ceases, but the increasing intensity of these determining folds southwards invites the speculation that the primary cause of the separation of England from the Continent was the establishment of a west-to-east line of drainage analogous to those of the Thames and the Frome, and the subsequent invasion of that line by the sea. It must be remembered, however, that the English Channel does not follow the east-and-west structures consistently, but that it cuts across the Wealden Anticline in the Straits of Dover.

The objects, however, which I had more especially in mind in preparing this map were an illustration of the magnitude of the post-Oligocene movements, and of their effect upon the platform. The deepest hollow, as I have already mentioned, occurs in the Hampshire Basin, where the base of the Gault is estimated to lie more than 2500 feet below Ordnance datum. In the London Basin the greatest depth attained may amount to 1500 feet, in a small area 4 or 5 miles north of the Hog's Back. A depth of 1419 feet was proved in a deep boring close by. Between the two basins rises the anticline of the Weald. The ground in the Wealden area reaches an elevation of 803 feet above the sea at its highest point. I assume that the aggregate thickness of the part of the Wealden formation and the Lower Greensand which has been removed by denudation must have exceeded 700 feet, and that the elevation of the base of the Gault in the crown of the arch may be safely put at not less than 1500 feet. It follows that the difference in level in the base of the Gault caused by the post-Oligocene movements is not less than 3000 feet as between the Wealden Anticline and the London Basin, and not less than 4000 feet as between that anticline and the Hampshire Basin. These are large figures, and in face of them we are compelled to assume that the platform cannot have escaped warping through the post-Oligocene movements, even though it may have stood firm against the more trivial folding and faulting suffered by the Secondary rocks.

Having now gained some conception of the magnitude of the latest movements, we may endeavour to ascertain what the form of the platform would be if those effects were eliminated: in other words, to ascertain what its form was at the commencement of Upper Cretaceous time. For this purpose we combine the two maps (Pls. A & B), and by their aid correct the elevation or depression undergone at every known point on the platform.

Pl. B shows what correction is necessary at any spot to bring the base of the Gault to horizontality at present sea-level. The same correction made in the depth to the platform at the corresponding points on Pl. A will restore those points to the relative levels which they held when the Gault was deposited. Thus all the points where the Gault rests directly upon the platform will be indicated by the figure 0. At the Richmond boring, where the base of the Gault lies at 1122 feet below Ordnance datum, the

depth to the platform must be diminished by that amount, and will be indicated by −98 instead of −1220 feet; while in the Calvert and Bletchley borings, where the Gault no longer exists, but where its base is estimated to have been 700 feet above sea-level, the respective depths to the platform must be increased by that amount, and become −853 and −859 feet instead of −153 and −159 feet. The map forming Pl. C shows the result of applying this correction to every point within, or close to, the area occupied by the Gault, at which the platform has been proved. It therefore reproduces the form which the platform would possess if the base of the Gault were a true plane at sea-level. In other words, it eliminates the effects of the post-Oligocene movements.

On comparing Pl. C with Pl. A we are able to realize that the form of the platform was much altered by those movements.

In the central portion of the map a tract of high elevation clearly defines itself under London, and reappears north-eastwards near Harwich.

The contouring between Harwich and Lowestoft now ranges north-north-eastwards along the slopes of that tract, instead of northwards.

The ridge apparently proved by the Calvert and Bletchley borings is no longer in evidence. Those places now appear as being situated on the north-western slopes of the elevated tract; nor is there any reason to doubt that the same slope extends south-westwards towards Burford, where I have inserted an estimate of −1300 to −1600 feet, on the supposition that the base of the Gault, if it still existed, would be between 500 and 800 feet above the sea. Thus the existence of a ridge in the Palæozoic platform is not in itself sufficient to prove the continuation of an ancient axis, such as that of Charnwood. On the other hand, the fact that Cambrian rocks constitute the platform at Calvert, and the probability that Charnian rocks were reached at Bletchley are highly significant of an old line of upheaval.

On the south side of the elevated tract the features of the platform increase in boldness. The upland ends in a great declivity which is well-defined from Dover past Penshurst, and has a gradient of upwards of 1 in 26. That its descent continues to a depth of more than 4000 feet is proved at Penshurst, but how much farther it may go is not known. Assuming, however, that 1500 feet is not an exaggerated estimate for the elevation of the base of the Gault in the crown of the Wealden arch, and taking this in connexion with the

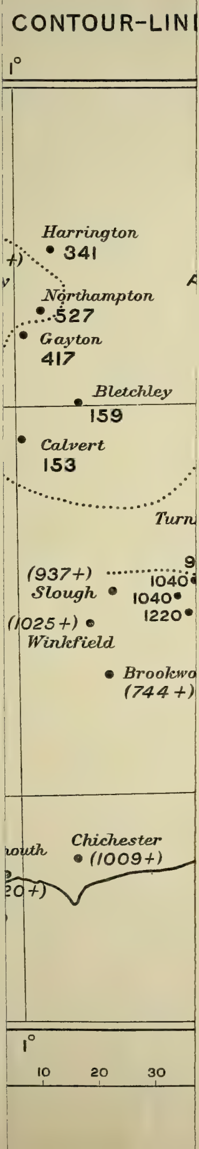
results of the Sub-Wealden boring, we are justified in supposing that the declivity shown by the —1000 and 1500-foot contours on the map represents the marginal part only of a prolonged slope. It is significant that the only boring which has reached the Palæozoic platform below the declivity shows the existence of Trias; at Brabourne 81 feet of marls and conglomerates lay unconformably on the steeply tilted Palæozoic rocks. It seems, therefore, that that formation circles round the elevated tract on its southern, as well as on its western and northern sides.

From this fact and from the development of the Jurassic rocks, it appears that the sag in the Palæozoic platform had been in progress more or less all through Mesozoic times, and that the superimposing of the Wealden Anticline upon it has been a minor incident upon the margin of the sagging area, not materially changing its character as a dominant factor in the structure of Southern England. It is remarkable, too, that the London syncline has been superimposed upon what had been for long a tract of elevation.

One of the results of the elimination of the post-Oligocene movements has been to accentuate the importance of the elevated tract of Eastern England at the expense of the Palæozoic areas of Western England and Wales: for, of course, the general tilt of the Upper Cretaceous rocks towards the west has been eliminated, as well as the synclines and anticlines. The evidence on which the relative levels of the London area and the western areas could have been estimated has perished with the denudation of the Upper Cretaceous rocks; but, if it is right to suppose that those rocks extended continuously over the western areas, we are confronted with a distribution of Palæozoic tracts in pre-Gault times which differs widely from the distribution now in existence.

At any rate, the existence of the elevated tract in early Cretaceous times explains several points that were obscure. It provides a probable source for some Palæozoic material which enters largely into the composition of some of the Lower Cretaceous rocks, and has clearly not travelled far. It explains also the attenuation of the Jurassic rocks and the littoral character assumed by them in its neighbourhood.

On the other hand, it must be admitted that there still is no obvious connexion between the configuration and the structure of the platform. Though little has been done as yet towards tracing the outcrops of the rocks which compose the Palæozoic platform, we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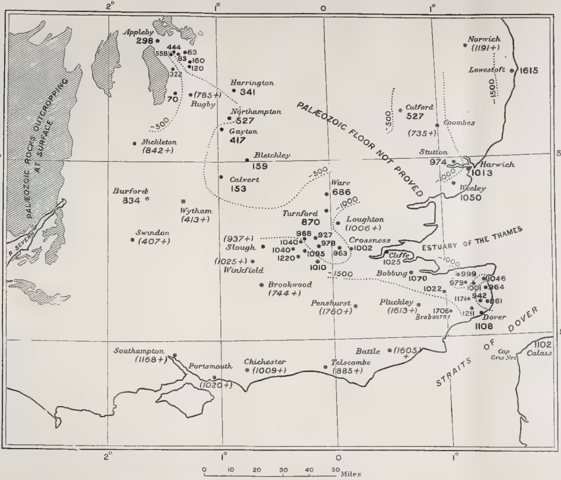
MAP OF BORINGS, SHOWING CONTOUR-LINES ON THE PALÆOZOIC PLATFORM.



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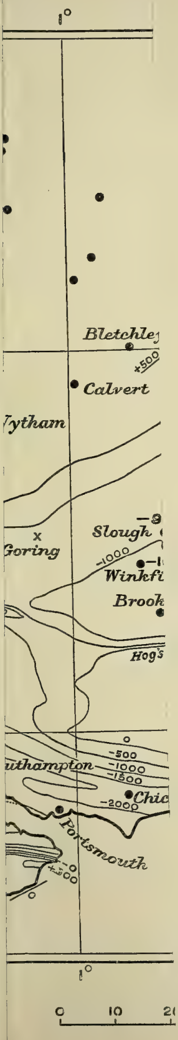
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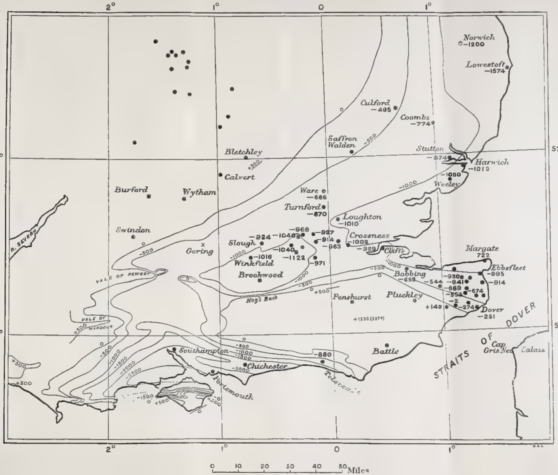
MAP SHOWING CONTOUR-LINES IN THE BASE OF THE GAULT.

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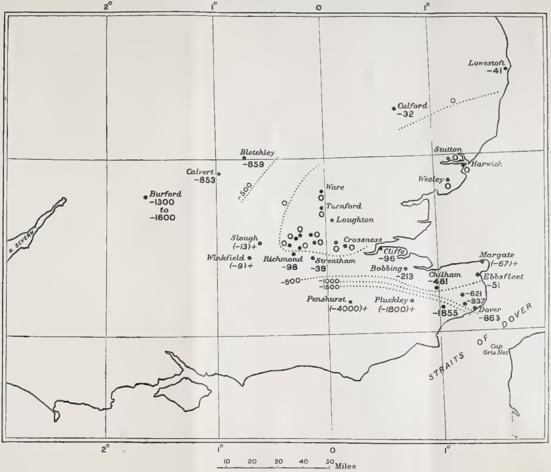
MAP SHOWING THE CONTOUR-LINES OF THE PALÆOZOIC PLATFORM CORRECTED FOR POST-CRETACEOUS MOVEMENTS.



know enough to be certain that there is little, if any, agreement between them and the contouring. The character of the platform seems to be attributable in the first place to marine planation and its form to subsequent warping.

For further pursuance of this method of investigation of the platform we must await the gathering of more evidence. So far as regards boring operations, no additional stimulus appears to be called for, so long as there remains a possibility of discovering workable coal. But I find here an opportunity of giving expression to an opinion which I have long held, that registration of deep borings in a Government Department should be made compulsory. In the Final Report of the Royal Commission on Coal-Supplies we inserted the following clause:—

'A large number of borings have been made in various parts of the country ranging to upwards of 3000 feet in depth. At present no machinery exists for preserving any information thus obtained, and we think it would be of great advantage if particulars of borings could be collected and preserved in a Government Office.'

This recommendation contemplates the inclusion of scientific results among the other particulars to be preserved, and on this account it might not be acceptable to explorers who for financial reasons were desirous of keeping to themselves the information which they had been put to expense to gain. There would probably be no difficulty in meeting the wishes of the explorers on this point; but, at any rate, the objection would not apply to the registration of other particulars. At present it is open to any member of the community, after agreement with the owner of the land, to bore a hole wherever he likes, as large as he pleases, as deep as he can go, and to leave no record. There can be no object in keeping the site, the diameter, or the depth of the hole secret; in fact it is not possible to do so. These particulars at least should be compulsorily registered, and the site of an important boring permanently marked. In one case at least a record, effective so far as it goes, has been made of the exact site, with other particulars, of a borehole. The site of a trial for coal at Foryd, near Rhyl, is marked by an inscribed stone, erected, I believe, by the Office of Woods & Forests.

It may be thought that a sufficient record is kept by the Geological Survey. As a fact, it is only through courtesy or by chance that we learn that borings are in progress. There are many

persons who feel strongly the desirability of records being preserved, and make a point of informing us when boring operations are undertaken; but it happens too frequently that we hear of a bore-hole having been made, too late for an adequate examination of the cores. Others we never hear of, nor are the cores submitted to any competent geologist; and in such cases records, if preserved at all, are apt to be worse than useless. Any hard rock is liable to be called granite; Lower Palæozoic shales, if they are black, become Coal Measures; all red rocks are New Red Sandstone. This is not the time for suggesting the exact form of the machinery which should be created for the preservation of boring records, but I take the opportunity of expressing to you my opinion that our methods of exploration are at present happy-go-lucky and unworthy of our great mineral heritage.

There are, however, other lines of investigation to which I wish to direct attention as offering a prospect of throwing more light upon the nature of the complicated mass of Palæozoic rocks which lies under our feet. As geologists, we learn with pleasure from the last Report of Progress of the Ordnance Survey that a revised levelling of the British Isles is in progress.

In the primary levelling, which was carried out in the years 1841 to 1859, the precision is not of a modern standard. The levels, moreover, were recorded by rough marks on various objects which were often not permanent. The new levelling has been planned with the object of determining relative altitudes with the utmost attainable precision, and of recording levels by permanent marks which are founded on rock below the subsoil, and are, so far as can be foreseen, free from suspicion of shifting from any cause whatever apart from movement of the earth's crust. Various difficulties, to which I need not now refer, arose in the selection of suitable sites for these 'fundamental points'; but in the levelling, when carried out with such precision as is contemplated, certain factors of unknown value may have to be taken into account. Among these I may mention the existence of earth-tides, and also the effect of the oceanic tide in temporarily depressing the coast upon which it impinges.

But what I have in my mind more especially is the variation in gravity which is known to exist, but has never been systematically investigated in the British Isles. A large number of observations on the deflection of the plumb-line and on the varying

rate of the pendulum, both due to variations in gravity, have been and are being made in various parts of the world, notably in Austria, Germany, America, and India. In India it has been stated that gravity is greater on islands than on the coast of the mainland, greater on the coast than inland, and greater on the plains than in the immediate neighbourhood of the Himalayas. Col. Burrard, by recent observations with the plumb-line, has shown that a line of high density crosses India in lat. 23° N., and that between this and the Himalayas exists a line of low density, or, as he terms it, a 'deep rift,' in the approach to which the change in the amount of deflection is remarkably rapid. The effects of the rift are so great as to obliterate the effects of topography and isostasy. So far as regards the immense alluvial plains of Northern India the plumb-line is deflected everywhere away from the mountains, and the deflections are in opposition both to the topography and the theory of isostasy.

The observations in Great Britain were carried so far as to indicate the existence of variations in gravity which were not to be explained by the configuration of the ground. Capt. A. R. Clarke, writing in 1858 on discrepancies in latitude when geodetically compared, concludes that

> 'it must be assumed that every latitude is affected by two distinct sources of disturbance: namely, superincumbent irregularly-disposed masses, and irregularities in the distribution of matter below the surface.'[1]

In the Isle of Wight he notices a southward deflection, whereas, from the mass of England to the north a northward deflection might have been anticipated (*op. cit.* p. 712): an interesting observation when taken in connexion with what is now known of the deflection on coast-lines. At Lough Foyle, Ben Hutig, and Edinburgh he found reason to infer 'that the plumb-line is drawn southward by dense subterranean masses.' At Blackdown in Dorset, Southampton, Greenwich, and in the Shetland Islands deflections were noticed which could not be accounted for by inequalities of the ground. At Portsoy, on the northern coast of Banffshire, there is a local but remarkably large disturbance of gravity which has not been explained.

The famous experiments on Schiehallion in 1772, and on Arthur's Seat in 1855, were made with the view of ascertaining to what

[1] 'Account of the Observations & Calculations of the Principal Triangulation, &c.' 1858, p. 706.

extent the plumb-line is deflected by the attraction of a prominent rock-mass. It appears that such experiments would be of little value, unless they were accompanied by observations on the variations in gravity in the surrounding region where such variations may exist; although the configuration of the ground gives no reason to suspect them.

I have quoted these observations made so many years ago, in order to show that the early observers realized the nature of the problems on which they were touching. How far their conclusions would be confirmed or modified by more precise modern methods I do not know; but, taken in connexion with what is being discovered in other parts of the world, the observations serve to prove that, so far as regards the British Isles, the investigations ceased at a critical stage. That there were variations in gravity was proved, and it was recognized that some other cause than inequalities of the surface must be looked for; but the extent and distribution of the disturbances have not been ascertained. A Gravity Survey seems clearly to be called for.

If such a survey were made, a comparison of the results with those of the various magnetic surveys of Great Britain and Ireland would be likely to yield much interest. The last of the magnetic surveys was carried out by Sir Arthur W. Rücker and Sir T. Edward Thorpe. In the reports published in the 'Philosophical Transactions' for 1890 and 1896 a map was presented, showing the relation between the magnetic and the geological features of the United Kingdom. In the words of the authors 'the magnetic indications appear to be quite independent of the disposition of the newer strata,' but it must also be admitted that their connexion with the form and geological structure of the Palæozoic platform, so far as these are known, is not obvious. On the other hand, instances are reported in Germany of coincidence between magnetic ridge-lines and lines of equal gravity that can hardly be accidental.

I may here remind you that, at the last meeting of the British Association a recommendation was made in Section A to the effect

'that it is desirable that a detailed Magnetic Survey of the British Isles, on the lines of Professors Rücker and Thorpe for the epoch of 1891, should now be repeated, in order to answer the question as to the local variations of the terrestrial magnetic elements within 25 years.'

I should regard a Gravity Survey as at least equally desirable.

In these brief remarks on a wide subject I have been able to mention only a few of the investigations on gravity which have been made. My object has been to show that in the best-mapped country in the world a great work remains to be done. The platform which we have had under consideration not only presents undulations, but is composed of a variety of rocks varying in specific gravity, for it includes ancient sediments, some lying horizontally, some highly inclined, in parts cleaved, with metamorphic and igneous masses in places. Having regard also to the insular character of Great Britain and its situation upon the margin of the European Continent, we seem to be confronted with a region in which a Gravity Survey is pre-eminently desirable.

List of Principal Borings in that Part of England which lies South of the Wash.

This list is founded in part on a Table which formed Appendix IV to Part IX of the Final Report of the Royal Commission on Coal-Supplies (1905), but contains many additions and some corrections. The literature on the borings is copious. In the list reference is made to the latest version, and to that in which references to previous literature are given. All measurements are given in feet. Those in square brackets have been added to the published accounts.

	One-inch Map. New Series.	*Height of surface above O.D.*	*Depth.*	*Depth to Coal Measures or older rocks.*	*References.*	*Formations passed through.*
Appleby	155	270	974	578	'Geology of the Leicester Coalfield' 1907, p. 333 (Mem. Geol. Surv.).	Trias, 578; Coal Measures, to 396.
Baggeridge Wood	167	......	......	......	Unpublished.	
Barfreston	290	193	2667	1224	'Das Kent-Kohlenfeld' Glückauf, No. 27, 6 July 1912.	Chalk, 687: Gault, 197: Lower Greensand, 46; Wealden, 33; Oolites, 261; Coal Measures, to 1443.
Batsford	217	abt. 380	1700	1021	Rep. Roy. Comm. Coal-Supplies, 1905, pt. ix, pp. 16 & 36.	Lias and Rhætic, $466\frac{1}{2}$; Keuper Marl, 481; Keuper Sandstone, 74; Coal Measures (abt.) $524\frac{1}{2}$; Silurian, to $154\frac{1}{2}$.
Battle (Sub-Wealden Exploration).	320	[300]	1905	......	'The Record of the Sub-Wealden Exploration' 1878. 'Jurassic Rocks of Britain' vol. v (1895) p. 346; & 'Water-Supply of Sussex' 1899, p. 65 (Mem. Geol. Surv.).	Purbeckian, 177; Portlandian, 115; Kimeridgian, 1273; Corallian, 241; Oxfordian, to 99.
Beckton	257	$12\frac{1}{2}$	1020	975	'London Wells' Mem. Geol. Surv. 1912, p. 96.	Tertiary, 128; Chalk, 647; Upper Greensand and Gault, 200; Old Red Sandstone, to 45.
Blean. *See* Herne Bay.						
Bletchley	220	260	419	......	Geol. Mag. 1889, p. 356; 'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. v (1895) p. 48.	Oxford Clay and Kellaways Rock; with 'granite,' probably as boulders, but indicating proximity of the old rocks.
Bobbing	272	120	1260	1190	Trans. Inst. M. E. vol. xliv (1913) p. 363.	Tertiary, 142; Chalk, 692; Gault, 144; Lower Greensand, 55 ft. 10 in.; Oolites, 156 ft. 2 in.; Silurian, to 70.

Bosworth Wharf	155	310	1364	754	Q. J. G. S. vol. xlv (1889) p. 31.	Keuper, 744; breccia, 10; Cambrian, to 610.
Boxley Grange	288	[? 550]	943	……	*Ibid.* vol. xlii (1886) p. 34.	Chalk, 916; Gault, 9; Lower Greensand, to 18.
Brabourne	289	215	2004	1921	'Mesozoic Rocks of Kent' Mem. Geol. Surv. 1911, p. 33.	Gault, 66; Lower Greensand, 237½; Wealden-Purbeck, 376½; Portlandian, 31; Kimeridgian, 262; Corallian, 342; Oxford Clay and Cornbrash (?), 191; Lower Oolites, 194; Lias, 140; Trias, 81; ? Devonian, to 83.
Brandon	184	[270]	366¼	340	Proc. Warwicksh. Field Club, 1890.	Superficial, 21; Keuper, 319; Coal Measures, to 26.
Brighton. *See* Telscombe.						
Burford	236	350	1410	1184	'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iv (1894) p. 303.	Lower Oolites, 90: Lias, 627; Trias, 467; Coal Measures, to 226.
Bushey	256	abt. 180	700	……	'Geol. of London' Mem. Geol. Surv. vol. ii (1889) p. 48.	Chalk, 691; Gault, to 9.
Calvert	219	290	1280	443½	Q. J. G. S. vol. lxix (1913).	
Carrow (Norwich)	161	15	1196 or 1206	……	'Geology of Norwich' Mem. Geol. Surv. 1881, p. 163.	Superficial, 12; Chalk, 1152 or 1146; Greensand and Gault, to 42 or 38.
Caterham	286	707	874	……	Trans. Croydon Micr. N. H. Club, 1886, p. 48.	Tertiary and Chalk, 456; Upper Greensand and Gault, 398½; Lower Greensand, to 19½.
Chartley	140	[400]	3500	……	Unpublished.	Superficial, 19; Keuper Marl, 882; marl and sandstone, 426; Bunter (supposed), 889; Carboniferous Limestone (supposed), dip high, to 1284.
Chatham Dockyard No. 2.	272	18	965	……	Q. J. G. S. vol. xlii (1886) p. 29.	Superficial, 27; Chalk, 682; Gault, 193; Lower Greensand, 41; Oxford Clay, to 22.
Chattenden Barracks	272	127	1165	……	Q. J. G. S. vol. xlii (1886) p. 33 & vol. xliii (1887) p. 198.	Tertiary, 290; Chalk, about 680; Gault, 192; Lower Greensand, to 3.
Cheshunt. *See* Turnford.						
Chichester (South Street)	317	[45]	1054	……	'Geology of Chichester' Mem. Geol. Surv. 1903, p. 31.	Superficial, 23; Tertiary, 157; Chalk, 790; [Chalk Marl], to 84.
Chilham	289	80[1]	1154	1102½	Trans. Inst. M. E. vol. xliv (1913) p. 362.	Superficial, 21; Chalk, 379; Gault, 224¼; Lower Greensand, 42; Oolites, 112¾; Lias, 23½; Silurian, to 51½.
Chislet	273	……	……	……	Unpublished.	
Chiswick	270	25	1300	1120½	'London Wells' Mem. Geol. Surv. 1912, p. 145.	Tertiary, 288; Chalk, 655; Gault, 177½; Old Red Sandstone, to 179½.
Chitty	273	……	……	……	Unpublished.	

[1] Incorrectly given as 40 in the paper referred to.

LIST OF PRINCIPAL BORINGS (*continued*).

	One-inch Map. New Series.	*Height of surface above O.D.*	*Depth.*	*Depth to Coal Measures or older rocks.*	*References.*	*Formations passed through.*
Cliffe	272	12	1063	1037	'Water-Supply of Kent' Mem. Geol. Surv. 1898, pp. 109, 382.	Alluvium, etc., $77\frac{1}{4}$; Chalk, $655\frac{3}{4}$; Gault, 208; Lower Greensand, 96; Silurian, to 26.
Clipston	142	190	2105	970	'Concealed Coalfield, Yorks & Notts' Mem. Geol. Surv. 1913, p. 84.	Trias, 970; Coal Measures, to 1135.
Coombs	207	[160]	895	......	'Guide to London' Mem. Geol. Surv. 1901, p. 21.	Superficial, $30\frac{1}{2}$ or 57; Chalk, $843\frac{1}{2}$ or 817; Upper Greensand and Gault, to 21.
Cosford Hill	153	217	$936\frac{3}{4}$	......	Unpublished.	
Cowpasture	155	[370]	545	433	Q. J. G. S. vol. xlv (1889) p. 31.	Keuper with 53 feet of breccia at the base, 433; Cambrian (Stockingford Shales), to 112.
Crossness	257	$6\frac{1}{2}$	1060	1008	'Geol. of London' Mem. Geol. Surv. vol. ii (1889) p. 66.	Superficial, 39; Tertiary, 98; Chalk, 684; Upper Greensand and Gault, 187; Old Red Sandstone, to 52.
Culford	189	110	$657\frac{1}{4}$	$637\frac{1}{2}$	Q. J. G. S. vol. l (1894) p. 488.	Chalk, 532; Gault, 73; Lower Greensand, $32\frac{1}{2}$; pre-Carboniferous rock, to $19\frac{3}{4}$.
Desford	155	400	537	372	'Leicestershire & South Derbyshire Coalfield' Mem. Geol. Surv. 1907, pp. 104, 347.	Keuper Marl and Sandstone, 372; red rocks of doubtful age, 88; Millstone Grit, 12; Carboniferous Limestone, $27\frac{1}{2}$; igneous rock (Warwickshire camptonite ?), to $37\frac{1}{2}$.
Dover No. 1 Shaft	306	50	1219	1158	'Mesozoic Rocks of Kent' Mem. Geol. Surv. 1911, pp. 5–32.	Chalk, 107; Gault, $135\frac{1}{2}$; Lower Greensand, 130; Wealden, 85; Kimeridge Clay, 44; Corallian, 210; Oxford Clay with Kellaways Rock, 123; Lower Oolites, 127; Lias, 38; Coal Measures, sinking in progress.
East Lavant	317	?195	1012	......	'Water-Supply of Sussex' Mem. Geol. Surv. Suppl. 1911, p. 177.	Upper Chalk, $597\frac{1}{2}$; Middle Chalk, $212\frac{1}{2}$; Lower Chalk, to 202.
Ebbsfleet	274	10	1389	1056	'Summary of Progress for 1911' Mem. Geol. Surv. 1912, p. 70.	Tertiary, etc., 110; Chalk, 785; Gault, 110; Lower Greensand, 36; Wealden, 15; Coal Measures, 103; Carboniferous Limestone, to 230.

Elham. *See* Ottinge.						
Ellinge	289	465	$1805\frac{2}{3}$	$1676\frac{1}{3}$	Rep. Roy. Comm. Coal-Supplies, 1905, pt. x, p. 30.	Chalk, $557\frac{3}{4}$; Upper Greensand and Gault, $180\frac{3}{4}$; Lower Greensand, $58\frac{3}{4}$; Wealden, $62\frac{1}{3}$; Purbeck, $67\frac{1}{2}$; Oolites, 695; Lias, 54; Coal Measures, to $129\frac{1}{3}$.
Elmsthorpe	169	300	1440	460	Rep. Brit. Assoc. 1875, p. 137.	Superficial, 10; Keuper Marl, 120; Keuper Sandstone, 330; Coal Measures, to 980.
Four Ashes	153	......	......	......	Unpublished.	
Fredville	289	259	1813	$1368\frac{1}{2}$	Trans. Inst. M.E. vol. xliv (1913) p. 359.	Chalk, 800; Gault, 148; Lower Greensand, 51; Purbeck-Wealden, 36; Oolites, 323; Lias, $10\frac{1}{2}$; Coal Measures, to $444\frac{1}{2}$.
Gayton. *See* Northampton.						
Goodnestone	289	136	2881	1188	'Das Kent-Kohlenfeld,' Glückauf, No. 27, 6 July 1912.	Chalk, 780; Gault, 181; Lower Greensand, 42; Wealden, 43; Oolites, 142; Coal Measures, to 1693.
Harrington. *See* Orton.						
Harwich	224	16	1098	1029	'Geol. of East Essex' Mem. Geol. Surv. 1877, p. 23.	Superficial, 25; Tertiary, 53; Chalk, 890; Upper Greensand and Gault, 61; Silurian or older, to 69.
Hathern Village	141	130	879	$516\frac{1}{3}$	'Leicestershire & South Derbyshire Coalfield' Mem. Geol. Surv. 1907, p. 358.	Trias, $516\frac{1}{3}$; Carboniferous Limestone shales, to $362\frac{2}{3}$.
Hathern Station	141	135	402	402	*Ibid.* p. 359.	Trias, 402; 'Forest Rock' (Charnian) touched.
Herne Bay	273	[abt. 90]	......	......	Unpublished.	
Holkham Hall, Wells ...	130	30	713	......	'Geology of Fakenham' Mem. Geol. Surv. 1884, p. 51.	Superficial 20 (or 27); Chalk, 635 (or 657); Gault, 18; Lower Greensand, 70 (or 50); Kimeridge Clay?
Hothfield	289	200	800	......	Rep. Roy. Comm. Coal-Supplies, 1905, pt. x, p. 30.	Lower Greensand, 180; Wealden-Purbeck, 612; Portlandian, to 8.
Kentish Town	256	186	1302	$1113\frac{1}{2}$	'Geol. of London' Mem. Geol. Surv. vol. ii (1889) p. 124.	Tertiary, $324\frac{1}{2}$; Chalk, 645; Upper Greensand and Gault, 144; Old Red Sandstone, to $188\frac{1}{2}$.
Kersley	169	......	......	......	Unpublished.	
Kingshill Spinney	155	300	1054	848	'Leicestershire & South Derbyshire Coalfield' Mem. Geol. Surv. 1907, p. 344.	Superficial, 126; Keuper Marl, 246; Keuper Sandstone, 322; Bunter, 154; Cambrian, to 206.
Langley Green	168	......	......	......	Unpublished.	
Leicester (Crown Hill) ...	156	[310]	1000	837	'Geology of Leicester' Mem. Geol. Surv. 1903, p. 63.	Lias, 189; Rhætic and Keuper Marl, 542; Keuper Sandstone, 106; Cambrian, to 163.
Lindridge (Boring)	155	325	384	270	'Leicestershire & South Derbyshire Coalfield' Mem. Geol. Surv. 1907, p. 344.	Keuper, 270; Cambrian or older, to 114.

List of Principal Borings (*continued*).

	One-inch Map. New Series.	*Height of surface above O.D.*	*Depth.*	*Depth to Coal Measures or older rocks.*	*References.*	*Formations passed through.*
Lindridge (Shaft)	155	325	507	258	'Leicestershire & South Derbyshire Coalfield' Mem. Geol. Surv. 1907, p. 345.	Keuper, 258; red marl and limestone, 18; Coal Measures, to 231.
Loughton	257	[90]	1096	......	'Geol. of London' Mem. Geol. Surv. vol. ii (1889) p. 20.	Tertiary, 243; Chalk, 651; Upper Greensand and Gault, to 202; Lower Greensand? touched.
Lower Lemington. *See* Batsford.						
Lowestoft	176	12	1832	1627	'Summary of Progress for 1912' Mem. Geol. Surv. 1913, Appendix.	Superficial, 74; Crag, 166; London Clay, 160; Reading Beds, 75; Chalk, 1055; Upper Greensand & Gault, 56; Lower Greensand, 41; Silurian or Ordovician, to 205.
Lullington	155	275	1190	......	'Leicestershire & South Derbyshire Coalfield' Mem. Geol. Surv. 1907, p. 352.	Trias.
Lydden Valley	290	......	......	......	Unpublished.	
Maidenhead	255	abt. 140	......	......	Unpublished.	Starting in Upper Chalk; in progress in Gault at 900.
Margate	274	[60]	850	......	'S.E. Naturalist' 1902, p. 56.	Chalk, 719; Gault, $63\frac{1}{2}$; Lower Greensand, to $67\frac{1}{2}$.
Mattice Hill	290					
Maydensole	290					
Meux's Brewery	256	$85\frac{1}{2}$	1144	1061	'Geol. of London' Mem. Geol. Surv. vol. ii (1889) p. 165.	Superficial, 21; Tertiary, $135\frac{1}{2}$; Chalk, $655\frac{1}{2}$; Upper Greensand, 28; Gault, 160; Lower Greensand, 64; Upper Devonian, to 80.
Mickleton	200	[500]	1342	......	'Jurassic Rocks of Britain' Mem. Geol. Surv. vol. iii (1893) p. 156.	Lias, 1241; Rhætic, 74; Keuper Marl, to 27.
Mile End	256	[40]	875	......	'Geol. of London' Mem. Geol. Surv. vol. ii (1889) p. 134.	Superficial, $20\frac{1}{2}$; Tertiary, $180\frac{1}{2}$; Chalk, 654; Upper Greensand, to 20.
Mountford. *See* Battle.						
Netherford. *See* Battle.						

Northampton (Gayton) ...	202	282	994	699	Q. J. G. S. vol. xl (1884) pp. 485, 495; and Proc. Inst. C. E. vol. lxxiv, p. 270.	Lias and Rhætic, 617; Keuper Marl, $59\frac{1}{2}$; [? Triassic] littoral deposit, $22\frac{1}{2}$; Carboniferous Limestone shales, etc., 190; Old Red Sandstone (supposed), to 105.
do. (Kettering Road).	185	278	851	$805\frac{1}{2}$	Q. J. G. S. vol. xl (1884) pp. 484, 495.	Oolites, 18; Lias, 720; [? Triassic] sandstones, &c., $67\frac{1}{2}$; Carboniferous Limestone, to $45\frac{1}{2}$.
do. (Kingsthorpe, $2\frac{1}{2}$ miles N.E. of Northampton)	185	374	967	......	*Ibid.* pp. 482, 495.	Oolite, 120; Lias, 760; sandstones, marls, &c., to 87.
Norwich. *See* Carrow.						
Old Soar	287	[200]	858	......	Rep. Roy. Comm. Coal-Supplies, 1905, pt. x, p. 30.	Lower Greensand, 50; Wealden-Purbeck, to 808.
Orton	170	374	789	715	Q. J. G. S. vol. xl (1884) pp. 491, 495.	Lias, 666; Rhætic, 22; sandstones, marls, and breccia, 27; quartz-felsite, to 74.
Ottinge (Elham)	289	300	$835\frac{3}{4}$	......	Rep. Roy. Comm. Coal-Supplies, 1905, pt. x, p. 30.	Chalk, 170; Upper Greensand & Gault, 132; Lower Greensand, 213; Wealden-Purbeck, 195; Portlandian, $17\frac{1}{4}$; Kimeridgian, to $108\frac{1}{2}$.
Owthorpe	142	200	2032	1069	'Concealed Coalfield Yorks & Notts' Mem. Geol. Surv. 1913, p. 108.	Lias, $12\frac{1}{2}$; Rhætic and Trias, $1056\frac{1}{2}$; Coal Measures, to 963.
Oxney	290	......	......	......	Unpublished.	
Packington	168	......	......	......	Unpublished.	
Penshurst	287	85	1867	......	'Mesozoic Rocks of Kent' Mem. Geol. Surv. 1911, pp. 66–77.	Wealden, 552; Purbeck, 562; Portland Beds, 131; Kimeridge Clay, to 622.
Pluckley	288	105	1687	......	*Ibid.* pp. 57–65.	Wealden, 990; Purbeck, 101; Portland Beds, 70; Kimeridge Clay, to 526.
Portsmouth Dockyard ...	331	......	$1034\frac{1}{2}$	......	'Water-Supply of Hampshire' Mem. Geol. Surv. 1910, p. 117.	London Clay, $288\frac{1}{2}$; Reading Beds, 119; Chalk, to $626\frac{3}{4}$.
Richmond	270	17	$1444\frac{1}{2}$	1237	'Geol. of London' Mem. Geol. Surv. vol. ii (1889) p. 214.	Tertiary, 252; Chalk, 670; Upper Greensand and Gault, $217\frac{1}{2}$; Lower Greensand, 10; Oolites, $87\frac{1}{2}$; Old Red Sandstone, to $207\frac{1}{2}$.
Ripple	290	......	......	......	Unpublished.	
Ropersole	289	400	2129	$1574\frac{1}{2}$	Trans. Inst. M. E. vol. xliv (1913) p. 372.	Chalk, 834; Gault, 119; Lower Greensand, 72; Wealden, 65; Oolites, 463; Lias, $21\frac{1}{2}$; Coal Measures, to $554\frac{1}{2}$.
Ruddington	142	[120]	$1875\frac{1}{2}$	698	Rep. Roy. Comm. Coal-Supplies, 1905, pt. ix, App. iii.	Trias, marl, $414\frac{1}{4}$; sandstone, $283\frac{3}{4}$; Coal Measures, $452\frac{1}{2}$; Millstone Grit, to 725.

List of Principal Borings (*continued*).

	One-inch Map. New Series.	*Height of Surface above O.D.*	*Depth.*	*Depth to Coal Measures or older rocks.*	*References.*	*Formations passed through.*
Rugby	184	[360]	1145	......	Rep. Rugby School Nat. Hist. Soc. 1866, p. 41; Rep. Brit. Assoc. 1887, p. 364.	Lias, 400; Rhætic and Keuper Marl, 740; Keuper Sandstone, to 5.
Saffron Walden	205	[200]	1004	......	'Geol. of N.W. Essex' Mem. Geol. Surv. 1878, p. 79.	Chalk, 275; Chalk Marl, Gault, Lower Greensand, Kimeridge Clay, and Oxford Clay, to 729.
Sandwich. *See* Mattice Hill and Lydden Valley.						
Sapcote	169	350	$1654\frac{1}{2}$	470	Q. J. G. S. vol. xlv (1889) p. 30.	Keuper, about 470; Coal Measures, $210\frac{1}{2}$; Cambrian, to 974.
Sheerness	272	13	$940\frac{3}{4}$	......	'Water-Supply of Kent' Mem. Geol. Surv. 1908, p. 192.	Superficial, 87; Tertiary, 423; Chalk, to $470\frac{3}{4}$.
Slough	255	100	1037	......	Unpublished.	Superficial, 25; Tertiary, 54; Chalk, 778 ft. 10 in.; Gault, 166 ft. 2 in.; Lower Greensand, to 13.
Smestow	167	......	......	......	Unpublished.	
Snowdown. *See* Fredville.						
Southampton Common	315	145	$1313\frac{1}{2}$	......	'Geol. of Southampton' Mem. Geol. Surv. 1902, p. 59.	Tertiary, $454\frac{1}{2}$; Chalk, to 859.
Spring Pools	169	......	......	......	Unpublished.	
Standon	189	......	......	......	Unpublished.	
Stoke (Copsewood Grange)	169	[240]	169	142	Proc. Warwickshire Field-Club, 1890.	Keuper Marl, 60; Waterstones, 82; Upper Coal Measures, to 27.
Stodmarsh	273	87	1929	1066	'Das Kent-Kohlenfeld' Glückauf, No. 27, 6 July 1912.	Tertiary and Chalk, $771\frac{1}{2}$; Gault, $245\frac{1}{3}$; Oolites, 49; Coal Measures, to 863.
Stonehall	290	......	......	......	Unpublished.	
Stratford-on-Avon	200	[140]	804	......	Geol. Mag. 1896, p. 54.	Keuper.
Streatham Common	270	[110]	1271	1120	'Geol. of London' Mem. Geol. Surv. vol. ii (1889) p. 224.	Tertiary, $241\frac{1}{2}$; Chalk, 623; Upper Greensand and Gault, 217; Oolites, $38\frac{1}{2}$; Old Red Sandstone, to 151.

Streetley	154	abt. 450	1907	77	'Summary of Progress for 1911' Mem. Geol. Surv. 1912, p. 27.	Trias, 77; 'Permian' [Upper Carboniferous], to 1830.
Stretton Baskerville	169	[300]	681	622½	Rep. Roy. Comm. Coal-Supplies,' 1905, pt. ix, p. 45.	Superficial, 130; Keuper Marl, 242; Lower Keuper Sandstone, 250½; 'Whinstone' [Caldecote Series], to 58½.
Strood	272	15	757	......	Q. J. G. S. vol. xliii (1887) p. 204.	Superficial, 42; Chalk, 505; Gault, over 195; Lower Greensand, nearly 15.
Stutton	224	20	1525½	994	Rep. Roy. Comm. Coal-Supplies, 1905, pt. xi, App. i, p. 6.	Superficial, 16; Tertiary, 54; Chalk, 874½; Gault, 49½; Silurian ?, to 531½.
Sub-Wealden Exploration. *See* Battle.						
Swindon	252	329	736	......	Q. J. G. S. vol. xlii (1886) p. 287.	Kimeridge Clay, 72; Corallian, 40; Oxford Clay and Kellaways Rock, 572¾; Cornbrash, 18¼; Forest Marble, to 33.
Telscombe	318	[400]	1285	......	'Water-Supply of Sussex' Mem. Geol. Surv. 1899, p. 83.	Chalk, 958; Upper Greensand and Gault, 322; Lower Greensand, to 5.
Tottenham Court Road. *See* Meux's Brewery.						
Trapham	289	59	2685	1124	'Das Kent-Kohlenfeld' Glückauf, No. 27, 6 July 1912.	Chalk, 858; Gault, 42; Lower Greensand, 97; Oolites, 127; Coal Measures, to 1561.
Turnford	239	110	1010	980½	Q. J. G. S. vol. l (1894) p. 508.	Superficial and Tertiary, 102½; Chalk, 680½; Upper Greensand, 44; Gault, 153½; Devonian, to 29½.
Waldershare	290	325	2654	1394	Trans. Inst. M. E. vol. xliv (1913) p. 358.	Chalk, 820; Gault, 156; Lower Greensand, 70; Purbeck-Wealden, 42; Oolites, 301; Lias, 5; Coal Measures, etc., to 1260.
Walmestone	289	......	......	......	Unpublished.	
Ware	239	110	831½	796½	Q. J. G. S. vol. l (1894) p. 506.	Superficial, 17; Chalk, 573; Upper Greensand, 40; Gault, 166½; Silurian, to 35.
Weeley	224	[45]	1200	1094½	Rep. Roy. Comm. Coal-Supplies, 1905, pt. xi, App. i, p. 1.	Tertiary, 196; Chalk, 822½; Gault, 76; Silurian ?, to 105½.
Willesden (Stonebridge Park).	256	130	2000	1098	'London Wells' Mem. Geol. Surv. 1912, p. 184.	Tertiary, 256; Chalk, 590; Gault, 252; Old Red Sandstone, to 902.
Willesden (Park Royal)	256	113	1180½	1153	*Ibid.* p. 186.	Tertiary, 360; Chalk, 575; Gault, 218; Old Red Sandstone, to 27½.
Winkfield (New Lodge)	269	218	1243	......	'Water-Supply of Berks' Mem. Geol. Surv. 1902, p. 95.	Tertiary, 214; Chalk, 725; Upper Greensand and Gault, 295; Lower Greensand, to 9.
Woodnesborough	290	55	2242	1073	'Das Kent-Kohlenfeld' Glückauf, No. 27, 6 July 1912.	Tertiary and Chalk, 813; Gault, 155; Lower Greensand, 83; Oolites, 22; Coal Measures, to 1169.
Wytham	236	[220]	633	......	'Water-Supply of Berks' Mem. Geol. Surv. 1902, p. 103.	Superficial, 15; Oxford Clay and Kellaways Rock, 258; Cornbrash, Forest Marble, Great and Inferior Oolite, 175; Lias, to 185.

February 26th, 1913.

Dr. AUBREY STRAHAN, F.R.S., President, in the Chair.

Arthur Blakeney Coussmaker, c/o Johnson, Matthey & Co., 78 Hatton Garden, E.C.; Gordon Downes, B.Sc., Roseneath, Bromley Road, West Bridgford (Nottinghamshire); John Spencer, Assoc.M.Inst.M.E., 212 Blackburn Road, Accrington; and Frank Charles Thompson, B.Sc., Demonstrator in Geology in the University of Sheffield, 79 Wilkinson Street, Sheffield, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Geology of Bardsey Island (Carnarvonshire).' By Charles Alfred Matley, D.Sc., F.G.S.; with an Appendix on the Petrography by John Smith Flett, M.A., D.Sc., F.G.S.

2. 'The Loch Awe Syncline (Argyllshire).' By Edward Battersby Bailey, B.A., F.G.S.

Rock-specimens from Bardsey Island were exhibited by Dr. C. A. Matley, F.G.S., and Dr. J. S. Flett, M.A., F.G.S., in illustration of their paper.

March 5th, 1913.

Dr. AUBREY STRAHAN, F.R.S., President, in the Chair.

Herbert Crompton Rawsthorne, Assoc.M.Inst.C.E., Dunscar Fold, Bromley Cross (Lancashire), was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The "Kelloway Rock" of Scarborough.' By S. S. Buckman, F.G.S.

2. 'On Jurassic Ammonites from Jebel Zaghuan (Tunis).' By Leonard Frank Spath, B.Sc., F.G.S.

The following specimens and photographs were exhibited:—

Specimens and photographs, exhibited by S. S. Buckman, F.G.S., in illustration of his paper.

Specimens of Jurassic ammonites from Tunis, exhibited by L. F. Spath, B.Sc., F.G.S., in illustration of his paper.

March 19th, 1913.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

George Knox, Lecturer on Geology & Mining in the Wigan Mining College, 14 Swinley Road, Wigan; Gaston Félix Joseph Preumont, The Avenue, Bishop's Waltham (Hampshire); and Ernest R. Spragg, 134 The Avenue, Highams Park, Chingford (Essex), were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced that the Council had awarded the Proceeds of the Daniel Pidgeon Fund for the present year to Roderick Urwick Sayce, B.A., University College of Wales, Aberystwyth, who proposes to investigate the rock-succession and structure of the Ystwyth Valley and its neighbourhood.

The following communications were read:—

1. 'The Geology of Northern Peru: Tertiary and Quaternary Beds.' By Beeby Thompson, F.G.S., F.C.S.

2. 'The Internal Cranial Elements and Foramina of *Dapedius granulatus*, from a Specimen recently found in the Lias at Charmouth.' By George Allan Frost, F.G.S.

The following specimens, etc. were exhibited:—

Specimens, photographs, and lantern-slides exhibited by Beeby Thompson, F.G.S., F.C.S., in illustration of his paper.

Skull of *Dapedius granulatus*, exhibited by G. Allan Frost, F.G.S., in illustration of his paper.

Manuscript geological map of Southern Rhodesia, exhibited by F. P. Mennell, F.G.S.

April 9th, 1913.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

A letter was read from Prof. F. D. Adams, President of the 12th International Geological Congress, expressing the hope that Fellows of the Society and British geologists in general would be largely represented at the Congress, which is to be held in Canada

next August. He added that every endeavour is being used to make the Congress a success, and that excursions have been arranged to almost every accessible part of the Dominion.

The following communications were read :—

1. 'The Variation of *Planorbis multiformis* Bronn.' By George Hickling, D.Sc., F.G.S., Lecturer in Palæontology & Demonstrator in Geology in the Victoria University of Manchester.

2. 'The Structure and Relationships of the *Carbonicolæ*.' By Miss M. Colley March, M.Sc. (Communicated by Dr. G. Hickling, F.G.S.)

Lantern-slides were exhibited by Dr. G. Hickling, F.G.S., in illustration of his paper.

A Special General Meeting was held at 7.45 P.M. (before the Ordinary Meeting), at which

(1) the retirement on pension of the Assistant-Librarian, Mr. William Rupert Jones, was sanctioned; and

(2) the appointment as Assistant-Clerk of Mr. Maurice St. John Hope was confirmed.

April 23rd, 1913.

Dr. AUBREY STRAHAN, F.R.S., President, in the Chair.

Thomas Dewhurst, Assoc.R.C.S., 131 Rectory Road, Burnley (Lancashire); George Sheppard, Lecturer in Geology at the Hull Technical College, Sunny Bank, Withernsea (Yorkshire); Alfred Leo Simon, Ph.D., Arundel, The Park, Sidcup (Kent); Herbert Edward Taylor, 31 Mysore Road, Lavender Hill, Battersea, S.W.; David Thomas, c/o the Institution of Mining & Metallurgy, Salisbury House, E.C.; and Douglas Graeme Williams, Downderry, Crawstone Road South, Westcliff-on-Sea (Essex), were elected Fellows of the Society.

Prof. Dr. Émile Haug, Paris, and Dr. Per Johan Holmquist, Stockholm, were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

Prof. E. HULL described the large chart of the North Atlantic Ocean which was hung on the wall. This chart had been prepared to illustrate the paper which he had read at the Meeting of the International Zoological Congress held at Monaco in March, to show the mode of migration of animals by land-connexion between Europe and the American Continent, due to the great uplift of the

whole region by several thousands of feet during the Mio-Pleistocene Epoch. The chart showed at a glance the submerged structure of the ocean-bed and bordering coasts on both sides of the Atlantic, indicating a rise of 1000 to 1200 fathoms (6000 to 7200 feet) during the culminating stage of the Glacial Period. This was proved by the fact that the channels of the existing rivers—such as the Loire, the Adour, the Mondego, the Tagus, and the Congo—were continued down to the depths above named, across 'the Continental Platform' and 'the Great Declivity' to the floor of the Abyssal Ocean. The details had been worked out by means of the soundings taken from the Admiralty charts and the isobathic contours, the details of which are recorded, with the charts appertaining thereto, in the speaker's 'Monograph of the Sub-Oceanic Physiography of the North Atlantic Ocean.' In the view of the speaker this great uplift of the Northern Hemisphere was the *vera causa* of the Glacial Period or 'The Great Ice-Age' of Prof. James Geikie.

The following communications were read:—

1. 'On the Fossil Flora of the Pembrokeshire Portion of the South Wales Coalfield.' By Reginald H. Goode, B.A. (Communicated by Dr. E. A. Newell Arber, M.A., F.G.S.)

2. 'The Halesowen Sandstone Series of the Southern End of the South Staffordshire Coalfield; and the Petrified Logs of Wood found therein at Witley Colliery, Halesowen (Worcestershire).' By Henry Kay, F.G.S. With an Appendix on the Structure of a New Species of *Dadoxylon*, by E. A. Newell Arber, M.A., Sc.D., F.L.S., F.G.S.

In addition to the exhibit described on pp. xciv–xcv, the following specimens, maps, etc. were exhibited:—

Specimens and lantern-slides of Carboniferous plants from Pembrokeshire, exhibited in illustration of the paper by R. H. Goode, B.A.

Petrified logs of wood, etc. from the South Staffordshire Coalfield; also photographs, microscope-sections, and lantern-slides, exhibited by Henry Kay, F.G.S., in illustration of his paper.

Geological Survey of England & Wales: 1-inch Geological Map (n. s.) Sheet 349—Ivybridge (colour-printed), 1913. Presented by the Director of H.M. Geological Survey.

Geological Survey of Scotland: 1-inch Geological Map, Sheet 64—Kingussie (colour-printed), 1913. Presented by the Director of H.M. Geological Survey.

Geological Map of Victoria: 1 inch = 16 miles, 1912. Presented by the Director of the Geological Survey of that State.

Imperial Geological Survey of Japan: 1 : 200,000 Geological Map—Ichinohe, Kanazawa, Kiso, and Shichinohe, 1912. Presented by the Director of that Survey.

May 7th, 1913.

Dr. AUBREY STRAHAN, F.R.S., President;
and afterwards W. WHITAKER, B.A., F.R.S., F.G.S., in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Bathonian Rocks of the Oxford District.' By M. Odling, M.A., B.Sc., F.G.S.

2. 'On the Petrology of the Kalgoorlie Goldfield (Western Australia).' By James Allan Thomson, M.A., D.Sc., F.G.S.

Lantern-slides, rock-specimens, and microscope-sections were exhibited by M. Odling, M.A., B.Sc., F.G.S., in illustration of his paper.

May 28th, 1913.

Dr. AUBREY STRAHAN, F.R.S., President,
in the Chair.

Ernest Masson Anderson, H.M. Geological Survey, 43 Ladysmith Road, Edinburgh; John Edward Austin, F.R.A.S., West Court, Detling, near Maidstone; Harvey Collingridge, B.Sc., Assoc.M.Inst.C.E., Auburn, Denville, Havant; Arthur Francis Hallimond, B.A., Assistant Curator in the Museum of Practical Geology, 28 Jermyn Street, S.W.; John Ranson, Assoc.M.Inst.M.E., 174 Willows Lane, Accrington; Richard Daniel Thomas-Jones, 5 Park View, Broughton, near Manchester; William Henry Turton, M.B., C.M., Barlborough House, Heanor (Derbyshire); and George H. Uttley, M.A., M.Sc., High School, Oamaru (New Zealand), were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT, in referring to the loss which the Society had that day sustained by the decease of JOHN LUBBOCK, 1st Baron AVEBURY, recalled the fact that Lord Avebury had been a Fellow of the Society for no less than fifty-eight years, that he had contributed several valuable papers to the Society's Journal, and that he was the recipient of the first Prestwich Medal. The President added that he felt sure that the Fellows would associate themselves with the resolution of condolence and sympathy which the Council had addressed to Lady Avebury.

The following communications were read :—

1. 'On the Age of the Suffolk Valleys; with Notes on the Buried Channels of Drift.' By Percy G. H. Boswell, B.Sc., F.G.S.

2. 'The Internal Structure of Upper Silurian Rugose Corals from the Grindrod Collection, Oxford Museum.' By Donald Esme Innes, B.A. (Communicated by Prof. W. J. Sollas, Sc.D., F.R.S., F.G.S.)

The following specimens were exhibited :—

Examples of water-rolled flints, and a typical specimen of chalky silt, exhibited by P. G. H. Boswell, B.Sc., F.G.S., in illustration of his paper.

Specimens of Upper Silurian corals, with microscopic sections, exhibited in illustration of the paper by D. E. Innes, B.A.

Slab with numerous specimens of *Microdiscus punctatus*, from the Solva Beds, east side of Solva Harbour, accompanied by a photographic enlargement, exhibited by W. P. D. Stebbing, F.G.S.

Sponges from the Upper Chalk of Grays (Essex); also *Ostrea* with marks of attachment to the inner whorls of an ammonite, and *Exogyra* with colour-bands, from the Lower Chalk of Burham (Kent), exhibited by G. E. Dibley, F.G.S.

June 11th, 1913.

Dr. Aubrey Strahan, F.R.S., President;
and afterwards W. Whitaker, B.A., F.R.S., in the Chair.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The following communications were read :—

1. 'Certain Upper Jurassic Strata of England.' By Dr. Hans Salfeld, University of Göttingen. (Communicated by S. S. Buckman, F.G.S.)

2. 'The Volcanic Rocks of the Forfarshire Coast and their Associated Sediments.' By Albert Jowett, M.Sc., F.G.S.

3. 'On a Group of Metamorphosed Sediments situated between Machakos and Lake Magadi in British East Africa.' By John Parkinson, M.A., F.G.S.

The following photographs and specimens were exhibited :—

Photographs and specimens of Upper Jurassic ammonites, exhibited by S. S. Buckman, F.G.S., in illustration of Dr. Salfeld's paper.

Hand-specimens and rock-sections, exhibited by A. Jowett, M.Sc., F.G.S., in illustration of his paper.

Rock-specimens from British East Africa, exhibited by J. Parkinson, M.A., F.G.S., in illustration of his paper.

June 25th, 1913.

Dr. Aubrey Strahan, F.R.S., President,
in the Chair.

Frederick Hughes, 16 Park Crescent, Merthyr Tydfil; Irvine George Jardine, B.Sc., 32 Matthews Park Avenue, Stratford, E.; Frederick Henry Loury-Corry, B.A., Edwardstone Hall, Boxford (Suffolk); James Alec Mitchell, 46 Warwick Road, Ealing, W.; W. J. Reynolds, 19 St. Clair Avenue, Port of Spain (Trinidad); the Rev. W. J. Ryan, S.J., University of Innsbruck (Tyrol); Prof. Stephen Taber, Ph.D., Columbia (South Carolina), U.S.A.; Principal William Thomas, M.Inst.M.E., Glanffrwd, Cemetery Road, Porth (Glamorgan); and William Robert Watt, M.A., B.Sc., Schoolhouse, Knocklands (Morayshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

Mr. C. Dawson, F.S.A., F.G.S., exhibited zinc-blende occurring in ironstone nodules which contain plant-remains, in the celebrated plant-bed of the Fairlight Clays, Fairlight, near Hastings. He remarked that the form is crystalline and the ore is frequently found filling up cavities left by the decayed vegetable matter. Zinc-blende is not known to occur at other horizons in the Weald, nor anywhere else in the South-East of England. It is probably segregated from older rocks of which the Wealden strata are composed.

He also exhibited pisolitic limonite, which occurs in considerable quantities at one or two horizons in the Fairlight Clays, near Hastings. On the shore at Pett Level, near Fairlight Cliff-end,

a very large deposit is found, just above the ordinary high-water mark. The deposit consists of minute spherical grains or nodules of sand-like character. These, on being analysed, prove to contain 60 per cent. of iron-oxide. In the cliff the iron-ore occurs in bands, the grains of which it is composed forming a compact grey conglomerate which turns dark brown on exposure. Many pieces of the conglomerate are to be found on the shore in a rolled condition. When disintegrated, they are deposited by the joint action of the eastward drift of the tide and the south-westerly wind along the shore. The deposit last year measured about half a mile in length, by about 30 or 40 yards in width, and was 3 to 4 feet deep.

The following communication was read :—

'The Miocene Beds of the Victoria Nyanza and the Geology of the Country between the Lake and the Kisii Highlands.' By Felix Oswald, D.Sc., B.A., F.G.S. ; with Appendices on the Vertebrate Remains, by Charles William Andrews, D.Sc., F.R.S. ; on the Non-Marine Mollusca, by Richard Bullen Newton, F.G.S. ; and on the Plant-Remains, by Miss Bancroft.

In addition to the exhibits described on pp. xcviii–xcix, Lower Miocene mammalia and gasteropoda from the Victoria Nyanza, and rocks and stone-implements from the Nyanza Province, also Pleistocene mammalia from British East Africa, were exhibited in illustration of Dr. Felix Oswald's paper.

On Wednesday, June 18th, 1913, a Conversazione, at which about three hundred ladies and gentlemen were present, was held in the Society's Apartments, from 9 to 11.30 P.M. In the course of the evening, lectures, illustrated by lantern-slides, were delivered by Prof. W. W. Watts, F.R.S., on 'The Buried Landscape of Charnwood Forest,' and by Capt. H. G. Lyons, F.R.S., on 'The Marshes of the Upper Nile.' Many interesting exhibits were shown by Dr. R. Broom, Mr. G. M. Davies, Mr. G. E. Dibley, Dr. J. W. Evans, Mr. W. F. Gwinnell, the Rev. H. N. Hutchinson, Dr. J. S. Owens, Mr. J. Postlethwaite, Mr. T. W. Reader, Mr. W. P. D. Stebbing, Dr. Marie C. Stopes, Mr. Bristow J. Tully, Dr. A. Wade, Mr. T. H. Withers, Mr. W. Wright, and the Director of H.M. Geological Survey.

ADMISSION AND PRIVILEGES

OF

FELLOWS OF THE GEOLOGICAL SOCIETY OF LONDON.

Every Candidate for admission as a Fellow must be proposed by three or more Fellows, who must sign a Certificate in his favour. The Proposer whose name stands first upon the Certificate must have a personal knowledge of the Candidate.

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The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling-prices.

The Library is open daily to the Fellows between the hours of 10 and 5 (except during the fortnight commencing on the first Monday in September; see also next page), and on Meeting-Days until 8 P.M. Under certain restrictions, Fellows are allowed to borrow books from the Library.

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CONTENTS.

PAPERS READ.

[No. 277 of the Quarterly Journal will be published next March.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library at the Apartments of the Society is open every Weekday from Ten o'clock until Five, except during the fortnight commencing on the first Monday in September, when the Library is closed for the purpose of cleaning; the Library is also closed on Saturdays at One P.M. during the months of August and September. It is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.

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